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ENGINEERING ASSESSMENT

MHD RETROFIT STUDY

MILESTONE #3

CONFIGURATION ANALYSIS

MOUNTAIN STATES ENERGY INCORPORATED
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BUTTE, MONTANA 59702

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ENGINEERING ASSESSMENT

MHD RETROFIT STUDY

MILESTONE #3

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Mountain States Energy Inc.
POST OFFICE BOX 3662
BUTTE, MONTANA 59702
(406) 723-8182

83MSE-031

March 1, 1983

Mr. Robert J. Robinson
Deputy Director
Department of Natural Resources
and Conservation
32 South Ewing
Helena, MT 59601

Subject: Engineering Assessment - MHD Retrofit Study

Reference: Agreement Between DNRC and MSE, November 1, 1982.

Dear Mr. Robinson:

Submitted herewith are the results of Milestone #3, "Configuration Analysis", for the Engineering Assessment with regard to the MHD retrofit potential of an Advanced Test System to the J.E. Corette Plant in Billings, Montana.

Results and discussions of the analysis performed for the retrofit configuration accomplished for Milestone#2 are presented in Attachments 1 and 2. Attachment #3 depicts the Heat Recovery Seed Recovery (HRSR) configuration contemplated for the retrofit. This schematic has been forwarded to the Babcock and Wilcox Co. for review and comment.

Comments received from reviewers of the Milestone #2 effort are given in Attachment #5 and the MSE responses to the comments received are presented in Attachment 6.

The effort to complete Milestone #3 are summarized on Attachment #7 which constitutes an invoice for activities through February 18, 1983. Work on Milestone #4, "Determination of Design Requirements" was initiated on January 31, 1983.

If you have any questions, need additional information, or require any clarifications, please let me know.

Sincerely,

JMSherick

J. M. Sherick
President

EWA/JMS:klm

Attachments:
1. Configuration Analysis
2. Corette Retrofit Schematic D02-DNRC-001
3. Corette MHD Retrofit-Boiler D02-DNRC-002
4. Trip Report - Corette Plant Visitation
5. Reviewer Comments - Milestone #2
6. Comment Responses - Milestone #2
7. Invoice for Milestone #3
8. Cost Estimate for Milestone #4
9. Milestone Schedule and Status Report

ATTACHMENT 1

CONFIGURATION ANALYSIS

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1.0 EXECUTIVE SUMMARY

The objectives of Milestone 3 were as follows:

a. Perform detailed heat and mass balance calculations on the baseline design which was developed in Milestone 2.

b. Predict overall plant efficiency.

c. Develop a plant configuration which includes sizing of major MHD components and approximate steam flowrates from both the existing Corette and the MHD Heat Recovery System.

d. Identify design options which may require additional study.

All of these activities have been completed, and the overall conceptual design has been further defined. It can be characterized as a parallel boiler type of design with approximately 50% of steam generation from each boiler. The MHD generator is a supersonic channel which will produce 28 MW of electric power, and will use a 4.5T superconducting magnet. The Heat Recovery System is generally of conventional design and in addition to supplying the steam required for the Corette turbine, it also serves to preheat the oxidizer to a temperature of 1160°F. The method of steam tie-in to the existing plant is particularly simple and has been described in the Milestone 2 report. In summary, the design which is proposed here appears to be a workable one which meets the basic design requirements stated in References 2 and 3.

Since an important part of this study is to obtain an independent review of the ATS design, we are including as a separate attachment all of the written comments which MSE received from reviewers as a result of the Milestone 2 review. In addition, a response to these comments has been prepared by MSE, and is included as Attachment 6. The comments from reviewers were generally quite constructive, and in several cases resulted in design modifications which will improve the plant performance or simplify the design.

2.0 TECHNICAL OVERVIEW

As noted above the Milestone 2 report was reviewed by outside reviewers representing a cross-section of the MHD community and the utility industry. The written responses which were received are discussed in attachment 6. Two of the utility representatives addressed the design objectives which were identified in reference 1, and expressed particular concern about the first, the third and the fourth of these. As a result of their comments, and also as a result of the analysis efforts in Milestone 3, the first of these has been relaxed considerably while the fourth one has been retained. The requirement that seed reprocessing be demonstrated has also been dropped, since environmental constraints associated with the Corette site require that seed reprocessing be done off site. For completeness the revised four objectives are stated below.

1. Demonstrate that an MHD generator can attain at least 10% enthalpy extraction from the combustion gas flow.

2. Demonstrate that the heat recovery concepts which have been developed to date are workable. This should include demonstration of oxidant preheat and demonstration of the radiant and convective section of the heat recovery boiler.

3. Demonstrate that all critical MHD and Heat Recovery components can be designed to meet durability and reliability requirements for long duration operation with acceptable maintenance.

4. Achieve the same or greater overall plant efficiency as the original plant, with significantly increased net power output.

In developing a preliminary design for an MHD retrofit to the Corette plant it is also necessary to take into account several constraints which are imposed by the Corette plant itself, by the present technology base for MHD, or by the nature of what one wishes to accomplish in a demonstration project such as this. These are addressed in the following discussion.

a. The scale-up of MHD components is limited by the present technology base and test experience. The largest long-duration MHD test facility in this country is the Component Development and Integration Facility (CDIF), located in Butte, Montana. It is limited to the testing of MHD components which have a thermal input power rating of 50 MW or less. Since the Corette plant is rated at about 460 MW_{th}, the required scale-up is nearly an order of magnitude over existing components, if one assumes a full turbine powering from the MHD Heat Recovery System alone. Since such a large scale-up implies a high degree of uncertainty and risk, it becomes necessary to consider an alternative approach in which some fraction of the steam is supplied from the Heat Recovery System (HRS), with the balance being supplied by firing of the Corette boiler at a reduced rate.

b. There is a constraint on the Corette boiler which is imposed by efficiency considerations. The boiler should not be operated at below 45 percent of its rated output level in order to insure a reasonable plant heat rate. This constraint was imposed only for purposes of roughly sizing the HRSR System, and in no way precludes running the Corette boiler at below that level.

c. In order to minimize the capital expense as well as downtime due to construction, the retrofit design should impact the existing plant as little as possible, and maximum use should be made of existing plant equipment.

d. Because Corette is a base-loaded plant, the retrofit design must be compatible with this mode of operation. In particular, it should be possible to accomplish switchover from combined cycle to stand-alone steam plant operation, or vice-versa, within a few minutes.

The approach to the design task was to break the problem into two main parts; the MHD power train and the heat recovery system. The design point of the power train was determined by a parametric study that relied on a computer model of the generator. The objective was to determine the combination of preheat and oxygen enrichment that would yield an acceptable power output. The results and the study itself are described in section 2.1.

The heat recovery system design proved to be a more difficult task than the power train analysis, primarily because there is no known software which can adequately simulate either the complex geometry or the heat transfer phenomena that occur. The results of this design effort are summarized in section 3.

Based on the power train analysis and the Heat Recovery design specifications, an overall heat and mass balance for the plan has been calculated. In some cases the flow rates, temperatures, and pressures have been estimated from past experience or previous studies of similar retrofit design. The final heat and mass balance is shown in Attachment 2. The results are consistent with other retrofit studies except, perhaps for the fact that the design point operation will be at a slightly higher oxygen enrichment level (36 mole pct.) than might be expected. This is due to the assumption that the Air Separation Unit could use an internal compression process as described by Juhasz[5] to reduce the power requirement of the ASO compressor. A summary of all the important design point data is shown in Table 1. It should be noted that the retrofit schematic, Attachment 3, has been revised in a few places to take into account comments from reviewers. The flow-control valve for the superheat tie-in point has been eliminated, since it should be possible to control superheat flow by just controlling feedwater flow. Also, the seed processing loop has been eliminated, as noted above, and an error in flue gas circulation has been corrected. The cooling water paths have also been better defined.

TABLE 1

SUMMARY DESIGN POINT PARAMETERS
CORETTE ATS RETROFIT

1.	Thermal Input Power, MHD	250 MW	
	Thermal Input Power, Corette	234 ~~250~~ MW	
	Tot. Thermal Input		
2.	Coal Flow Rate, MHD		
	Coal Flow Rate, Corette		
3.	Coal: Montana Rosebud, dried to 5% moisture content, HHV = 10,735 BTU/lb.		
4.	MHD Power Output - Gross	28.44 MW	
	Total MHD Compr. Power	12.75 MW	
	Net MHD Power	15.68 MW	
	Corette Plant Output, Net	163.0 MW	
	Tot. Power Out, Net	178.7 MW	
5.	Overall Plant Efficiency 31% Conventional	36.9%	
6.	Enthalpy Extraction, MHD Gen.	12% ~~20.0%~~	
7.	Oxidizer Flows & Power Consumption:		
	Air Sep. Unit	14.92 kgm/sec	6.67 MW
	Blend Air Compr.	31.24 kgm/sec	6.09 MW
	Totals	46.16 kgm/sec	12.76 MW
8.	Combustor Pressure	5.85 Atm	
9.	Oxygen Content at ASU Exit	70 mole pct	
	Oxygen Content at Mixer Exit	36 mole pct	

2.1 Power Train Analysis

The performance of an MHD generator is dependent on a large number of design parameters which must be selected or evaluated to provide the desired performance. Selection of these parameters must also take into account cost and other constraints. Evaluation of these parameters is best accomplished using performance analysis computer codes which model the physical phenomena of the MHD process. The use of computer codes allows the variation of a large number of parameters and the use of complex equations modeling the physical process. Three codes have been used in the present analysis to model the MHD topping cycle of the retrofit system.

2.1.1 Modeling Approach

The performance of the combustor was modeled using the chemical equilibrium thermodynamics and transport properties computer program, CECTRN[6] to evaluate the combustion flame temperature and the nozzle exit conditions for each design case to be evaluated. CECTRN is a modified version of the familiar NASA Chemical Equilibrium Calculations computer program, CEC76[7]. The chemistry of the coal, seed, and oxidizer (air or oxygen enriched air) are specified for each run. Combustor and nozzle heat transfer are accounted for through an adjustment of the

specified enthalpy of the reactants. Three runs of the CECTRN program are required for each case to be evaluated. One run is made to determine the combustor flame temperature. An enthalpy adjustment accounting for the combustor heat transfer is entered in this run, since the flame temperature is dependent on this quantity. Another run is made to determine the fluid and thermodynamic conditions at the exit of the nozzle (entrance to the MHD channel). An enthalpy adjustment to account for both the combustor and the nozzle heat transfers is used in this analysis. The third run of CECTRN is made to produce a table of thermodynamic and transport properties including conductivity and mobility, that is to be used in the MHD channel and diffuser analyses to describe the "real gas" properties of the particular chemistry for each analysis.

The CECTRN program has several modes of operation, two of which are used in these analyses. The combustor flame temperature and the nozzle exit conditions are evaluated using the RKT (rocket) mode while the table of thermodynamic and transport properties are evaluated using the TP (temperature and pressure specified) mode. The RKT mode is really a special application of the HP (enthalpy and pressure specified) mode, in which the combustion pressure and the enthalpy of the reactants is specified allowing calculation of the reaction temperature. Also

provided in the RKT mode is the calculation of an isentropic expansion from the combustor condition to specified nozzle exit conditions. This is used to determine the MHD channel entrance conditions. The nozzle exit can be specified by the static to stagnation pressure ratio or by the ratio of the exit area to the nozzle throat area. The nozzle exit can also be specified as subsonic or supersonic.

The CECTRN code does not have provisions for specifying heat transfer. However, there is a technique by which the heat transfer can be taken into account if the heat transfer rate is known or can be assumed. For the present analysis, the heat transfer is assumed to be a fixed percentage of the fuel thermal input to the combustor. The heat transfer can then be expressed as an energy per mole of fuel (cal/mole for CECTRN input), and expressed as an adjustment to the enthalpy of the reactants. The flame temperature is calculated as an adiabatic flame temperature by assuming the enthalpy of the products of combustion to be equal to the enthalpy of the reactants. The flame temperature thus calculated is the true temperature accounting for heat transfer since the reactant enthalpy has been adjusted by the amount of the heat transfer.

The table of thermodynamic and transport properties is calculated by specifying 16 values of temperature and 6 values of pressure over the range of interest and calculating the chemical equilibrium composition and properties at each combination of temperature and pressure using the TP mode. The primary thermodynamic properties of interest are the specific heat (C_p, the isentropic exponent (gamma), the molecular weight, the enthalpy, and several thermodynamic derivatives. The desired transport properties include the viscosity and Prandtl number. The electrical conductivity and mobility are also calculated using the method of Demetriades and Argyropolous[8]. All of the properties calculated are tabulated in a data set that is saved for later use by the MHD channel analysis code.

The chemistry for input to the CECTRN code is calculated by another computer program, PLCOAL[9]. The ultimate and preliminary analyses for the particular coal to be used are specified in the PLCOAL input. The percentage of moisture in the dried coal and the percentage of ash to be rejected by the combustor are also specified. The program can then determine the relative quantities of ash, completely dried and ash free coal (daf coal), and water to be input to the CECTRN code to simulate the chemistry of the combustor exit flow. The oxidizer is specified to PLCOAL as either air or

air with a specified percentage of oxygen enrichment. The seed is specified as potassium carbonate and the quantity is determined by specifying the weight percentage of potassium in the MHD channel flow. From these inputs, PLCOAL determines all of the chemistry for the input to program CECTRN. By specifying the higher heating value, HHV, of the selected coal, PLCOAL is also able to calculate an enthalpy correction factor for use in the RKT mode of CECTRN to account for the difference between the theoretical HHV and the actual HHV.

The analysis of the MHD channel flow and the MHD performance is accomplished using a modified version of the quasi-one-dimensional channel code, MHDUTA, developed by D.R. Wilson at the University of Texas at Arlington.[10] This code uses a one-dimensional core flow solution coupled with an integral boundary layer solution on each of the four walls of the generator. The MHD differential equations of motion are solved by the program using a forth order, Runga-Kutta numerical integration technique. The numerical integration is a marching technique that solves for the fluid dynamics, thermodynamics, and electrical parameters at fixed intervals of axial distance from the entrance to the exit of the channel. The channel code can be run in either the design or off-design mode. In the design mode, the flow is described by specifying the axial

distribution of one of the design variables, temperature, pressure, velocity, Mach number, or core area. The program then solves the MHD equations to determine the geometric are axial distribution for the channel. In the off-design mode, the geometric area distribution is specified. The design variables are then the products of the solution.

The MHD channel code can be run for any one of the four types of MHD channels, i.e., segmented Faraday, Hall, diagonal conducting wall (DCW), or continuous wall Faraday. All of the designs for large scale efficient power production are based on either the segmented Faraday or DCW schemes. From the standpoint of the external wiring required, the DCW generator is a much less complex device than the Faraday. For simplicity, the DCW, two-terminal generator was chosen for the present analysis. All of the designs studied used a DCW generator with a wall angle of 45 degrees.

The design mode is used for the present design study. In all of the design cases studied, constant velocity solutions were used. Both subsonic and supersonic solutions were studied. Each design case was optimized for maximum design power by adjusting the load current I_L until a maximum power level was obtained. Figure 1 illustrates the effect of load current on design power for

a typical design. Each point on this curve represents a single MHD channel design, each different from the others, but all designed to meet the same specified design constraints at the specified design load current, I_L. The modified MHDUTA maximizes load current automatically by performing the MHD solution for a specified starting value of load current, then adjusting the load current through an iterative procedure until the maximum power is achieved. Each design case is thus optimized for maximum load power.

The total power generated and the total heat flux from the generator are calculated by integrating the local quantities over the axial length of the generator. The axial distribution of height, width, and area are outputs from the code that describe the geometry of the generator design. Axial distribution of the electrical parameters in the core flow including the axial and transverse current density and the axial and transverse electric fields are also results of the generator design.

For the present study, rather simple models of the diffusers were used. Supersonic diffuser pressure recovery was determined by assuming a normal shock at the exit conditions of the MHD generator. This is a conservative approach since a well designed supersonic diffuser should perform somewhat better than a normal shock recovery.

Subsonic pressure recovery was determined using a pressure recovery coefficient of 0.45. This value of the coefficient was estimated to be a reasonably conservative figure based on a paper by Doss[11] describing the performance of subsonic diffusers with high entrance blockage as is typical of MHD diffusers. The diffuser pressure recovery then determines the final exit conditions from the MHD topping unit. The pressure at the exit of the subsonic diffuser (entrance to the HRSR unit) must be sufficient to allow for the pressure drop that will occur in the HRSR unit and flue gas clean-up system. For the present study, a HRSR entrance pressure of 1.2 atm. was assumed.

The combustor total pressure for each analysis must be determined by iteration. Having selected a combustion pressure to begin the analysis, the combustor and nozzle conditions are elevated using CECTRN. The MHD performance is then analyzed using the modified MHDUTA. Finally, the diffuser pressure recovery and the pressure at the exit of the diffuser is calculated by the methods described above. If the diffuser exit pressure does not match the required constraint, a new combustion pressure is estimated, and the analysis process is begun again with CECTRN. Iteration is continued until a reasonable agreement in exit pressure is obtained. The final run is then the design for the conditions specified for that study.

2.1.2 Analytical Results

The present study has been directed toward the development of a reasonable conceptual design for a MHD retrofit of the Montana Power Company Corette Power Station. The concept recommended in this phase of the study is not the only concept that could be recommended for his application, nor is it necessarily the best from the standpoint of maximum thermal efficiency. However, within the constraints of the present study, the design here recommended has been determined to be a reasonable alternative.

Several design parameters have been selected at nominal values and fixed for the duration of the study. The fuel to be used for this study is Montana Rosebud Coal. The analysis of this coal is taken from the DOE Chemical Equilibrium Workshop study.[12] The coal is dried to 5 percent moisture by weight. The combustor is assumed to be capable of rejecting 85 percent of the ash. The remaining 15 percent of the ash is carried into and through the MHD channel and diffuser and finally into the HRSR unit. A carbon loss of 3 percent is assumed to be rejected along with the slag in the combustor. The seed stock for the present study is assumed to be potassium carbonate (K_2CO_3) in quantities that result in a 1.0 percent

concentration of potassium (by role) in the MHD generator flow. Heat flux from the combustor and nozzle were assumed to be 5 percent of the fuel thermal energy input.

Both subsonic and supersonic generators were studied. The subsonic generators were assumed to be constant velocity generators operating at a velocity of 800 m/s. Two inlet Mach numbers were considered for the supersonic cases. An inlet Mach number of 1.6 was considered but rejected early in the study due to poor performance. An inlet Mach number of 1.2 was used for the remainder of the study for the supersonic cases. The supersonic cases were also assumed to be constant velocity designs with a design velocity consistent with the specified inlet Mach number. For all subsonic cases, the peak magnetic field was assumed to be 6.0 Tesla. The peak magnetic field was 4.5 Tesla for all supersonic cases.

In all cases, the pressure at the exit of the subsonic diffuser was assumed to be 1.2 atmospheres. An iterative procedure was required to match this constraint.

The final parameter selected was the nominal size of the retrofit system to be considered. Various sizes from 100 MW fuel thermal input to 300 MW fuel thermal input were

discussed and considered. A unit of 250 MW fuel thermal input was finally selected and fixed for the remainder of the study. The size was selected based on scaling considerations and on a comparison of the relative sizes of the retrofit and primary Corette system.

First consider some limits on the size of a unit to be designed for installation on the Corette system. The unit could be designed to be sufficiently large so that it could supply all of the steam requirements of the present turbine, thus replacing the Corette boiler during the operation of the retrofit system. This would have the advantage of simplifying the interconnection of the retrofit and the existing Corette system and simplifying the control system of the retrofitted plant. However, there are a number of disadvantages as well. First, the system would be on the order of 500 MW fuel thermal input in size. This is a scaling factor of 10 to 1 over the present operating experience of MHD generators. It is felt that this is too large for the generator to be reasonably scaled. A 5 to 1 scaling factor is felt to be more reasonable for the first MHD retrofit. Furthermore, if the retrofit was providing the complete turbine supply, it would not be practical to keep the existing boiler hot. Thus, if a failure in the retrofit system caused complete

shut down, the existing boiler would require an excessive period of time for cold start to bring the plant back on line. Again, this is not felt to be a reasonable situation for the Corette power station.

A lower limit might also be considered for the retrofit. The lower limit would be one that could be operated with only a small perturbation on the operation of the Corette power station. This unit would be on the order of scale of the present CDIF channel, i.e. approximately 50 MW. This would provide no experience in scaling of MHD channels and for this reason, if for no other reason, would be considered impractical.

A design scaled to approximately five times that of CDIF would appear to be most practical while remaining reasonably conservative. This would be a unit of 250 MW thermal input. This size would have a secondary advantage as a retrofit on the Corette system. When the existing turbine is operating at full design output, the existing Corette boiler can continue to operate at 60 to 65 percent of design capacity, with only minimal loss of efficiency. With the existing Corette boiler operating at 60 percent, the plant could recover very quickly after a failure of the retrofit system. This retrofit would also be large enough to drive the turbine at about 50% output using only the

HRSR with the existing boiler down. This could provide good operating experience and some backup for Corette. The 250 MW unit is the most reasonable size for consideration of retrofit and has thus been selected for study in this analysis.

The design variables that have remained variable for this study are primarily the level of oxygen enrichment and the oxidizer preheat temperature. Also, both subsonic and supersonic designs have been considered. The combustion pressure varies from one design to the next. However, in any one design, the combustion pressure is constrained by the exit conditions. The combustion pressure is set for each design at the level that will provide the specified diffuser exit pressure of 1.2 atmospheres. The resulting combustion pressure does however have a large effect on the net power produced by the MHD unit.

The oxygen enrichment factor (OEF) was varied from 0 to 60 percent in this study. This corresponds to a variation of the molar nitrogen to oxygen ratio (N/O) from 3.727 to 1.5. The oxidizer preheat temperature was varied from 900 K (1160°F) to 1300 K (1880°F). The lower figure was chosen as a conservative figure for construction of heaters for highly enriched oxidizers, while the higher figure was chosen to represent the advanced state-off-the-art high temperature air preheaters as recommended by Stewart

Way[13]. The performance of MHD systems at various combinations of oxygen enrichment and preheat were studied and compared. Furthermore, these combinations were compared at both the supersonic and subsonic velocities.

2.1.3 Results

Six values of the N/O molar ratio were selected to compare in the present study. The six values are (with oxygen enrichment factor, OEF values shown in parentheses), 3.727 (0%), 3.0 (19.5%), 2.5 (32.9%), 2.0 (46.3%), 1.75 (53.1%), and 1.5 (59.8%). The first value listed, 3.727 (0%) is for air with no oxygen enrichment. Three values of oxidizer preheat were also considered, 900 K (1160°F), 1100 K (1520°F), and 1300 K (1800°F). The analysis codes were run to predict the performance of MHD topping units designed for various selected combinations of the oxygen enrichment and preheat values listed above. Figure 2 summarizes the results of these runs for the subsonic cases in the form of a performance map of MHD electrical power for variations of oxygen enrichment and preheat. The percent of total available enthalpy extraction is indicated on this map. The combustion total pressure is indicated in brackets by each point. A constraint line on the map indicates the portion of the map in which the combinations of oxygen enrichment and preheat can be achieved in a practical design.

Figure 3 is the performance map for the supersonic design cases. It can be seen from reviewing these two figures that the difference in performance between the subsonic cases and the supersonic cases for the design constraints of this study are minimal. The subsonic cases indicated slightly better performance in these analyses. It would be impossible to say from a comparison of this data that one is really better than the other at production of power from the MHD unit. They are very nearly the same in performance. However, there are other considerations that have led to the choice of the supersonic design.

The large scale experiments to date have been supersonic designs. The operation of supersonic channels is well understood. There are various control problems that may arise with large scale subsonic channels. These problems can be solved, but some experimentation may be necessary to develop the optimum design and control strategy for subsonic generators. The relative uncertainty in the design and control of subsonic channels and the lack of any substantial performance benefits dictates that a supersonic generator be used for this first retrofit.

The operation of MHD topping cycles require a relatively large combustion total pressure compared to the requirements of a conventional steam power plant. A significant amount of the produced MHD power must be used

for compression of the oxidizer flow to the MHD combustor. The energy requirements of an oxygen plant must also be considered if oxygen enrichment of the oxidizer is required. The net power of the MHD topping cycle for the supersonic cases is shown in Figure 4. The net power is the power produced in the MHD channel less the power requirements of the oxygen plant and oxidizer compressors.

The figures in brackets are the combustor total pressures required for the case. Two cases appear as competitors in this figure. The case having an oxygen enrichment factor of 53.1% with an oxidizer preheat of 900 K produces only slightly better performance than the case with no oxygen enrichment and an oxidizer preheat temperature of 1300 K. Of these two cases, the high oxygen enrichment case has been chosen for this retrofit study.

The reason for the choice of the high oxygen enrichment case over the high preheat temperature case is two fold. First, the high temperature (1300 K) air preheater is new technology and has not yet been proven. In fact, most manufacturers are reluctant to produce an air preheater for service at a temperature of greater than 1000 K. In a coal fired MHD environment, with the slag and highly corrosive potassium seed species present, the performance and durability of a high temperature air preheater are even more questionable. High temperature air preheaters of a

design such as that of Stewart Way may be well suited for future MHD designs. However, research, prototyping, and testing of these designs should be completed before they are considered for MHD applications.

The high oxygen enrichment design case also offers more flexibility than the high preheat case. For a first retrofit, flexibility in imperative. With an oxygen plant available, variation of the oxygen enrichment and preheat levels can be achieved. Some optimization and experimentation could be accomplished with the plant on line. The results of such variations would be very valuable to future design and scale-ups of the MHD topping units to commercial sizes.

The high oxygen enrichment case with an OEF of 53.1% (N/O of 1.75) and an oxidizer preheat of 900 K was thus chosen for the present design study. All of the cases shown in Figures 2 through 4 were run for an MHD channel active length of 10 meters. Without further study, it could not be certain that the channel length of 10 meters was optimal. Holding all other design parameters fixed except the combustion pressure, a variation of the length was made. The results of the performance study for MHD channel lengths from 10 to 14 meters is shown in Figure 5. A slight increase in MHD electrical power was achieved for the longer channels, but only at the expense of substantial

increases in combustor pressure. The increased oxidant compressor power would eliminate any small gains seen in the MHD electrical power. For this reason the 10 meter channel was chosen for this design.

The final specifications for the chosen channel are listed in Table 1. The calculated channel geometry is listed in Table 2.

TABLE 2

Selected MHD Channel and Topping Unit Specifications

Channel Type: Diagonal Wall

Channel Length: 10 meters

MHD Electrical Power: 28.7 MW

Peak Magnetic Field Strength: 4.5 T

Combustor: 250 MW Fuel Thermal Input
Heat Loss, 5% of Thermal Input
Slag Rejection, 85%
Combustion Pressure 5.85 atm.

Fuel: Montana Rosebud Coal, Dried to 5% H_2O
Mass flow rate, 10.01 kg/s (12.77 kg/s as rec'd.)

Oxidizer: Oxygen Enriched Air, OEF 53.1%, (N/O 1.75)
Mass Flow Rate, 46.16 kg/s
Preheat Temperature, 900 K
Air Separation Unit Mass Flow Rate, 14.92 kg/s
Air Separation Unit Oxygen Content, 71.85 mass pct.
Blend Air Mass Flow Rate, 31.24 kg/s

Seed: 1% k by weight using K_2CO_3
Mass Flow Rate of K_2CO_3, 0.992 kg/s

TABLE 3

Channel Geometry and Magnet Field Strength
250 MW Thermal, 53.1% Oxygen Enrichment, 900 K Oxidizer Preheat

X(m)	Area (M^2)	Width (M)	Height (M)	B (Telsa)
0.0	1.455D-01	3.814E-01	3.814E-01	4.500E-01
5.000D-01	1.540D-01	3.920E-01	3.928E-01	4.500E+00
1.000D+00	1.678D-01	4.085E-01	4.108E-01	4.500E+00
1.500D+00	1.828D-0-1	4.256E-01	4.295E-01	4.500E+00
2.000D+00	1.990D-01	4.434E-01	4.489E-01	4.500E+00
2.500D+00	2.166D-01	4.618E-01	4.691E-01	4.500E+00
3.000D+00	2.357D-01	4.809E-01	4.901E-01	4.500E+00
3.500D+00	2.563D-01	5.007E-01	5.119E-01	4.500E+00
4.000D+00	2.782D-01	5.209E-01	5.342E-01	4.500E+00
4.500D+00	3.014D-01	5.414E-01	5.567E-01	4.500E+00
5.000D+00	3.258D-01	5.621E-01	5.796E-01	4.500E+00
5.500D+00	3.514D-01	5.830E-01	6.027E-01	4.500E+00
6.000D+00	3.782D-01	6.041E-01	6.262E-01	4.500E+00
6.500D+00	4.061D-01	6.252E-01	6.496E-01	4.500E+00
7.000D+00	4.349D-01	6.462E-01	6.730E-01	4.500E+00
7.500D+00	4.645D-01	6.672E-01	6.962E-01	4.500E+00
8.000D+00	4.947D-01	6.879E-01	7.192E-01	4.500E+00
8.500D+00	5.253D-01	7.082E-01	7.418E-01	4.500E+00
9.000D+00	5.570D-01	7.285E-01	7.645E-01	4.500E+00
9.500D+00	5.892D-01	7.486E-01	7.871E-01	4.500E+00
1.000D+01	6.170D-01	7.655E-01	8.059E-01	4.500E-01

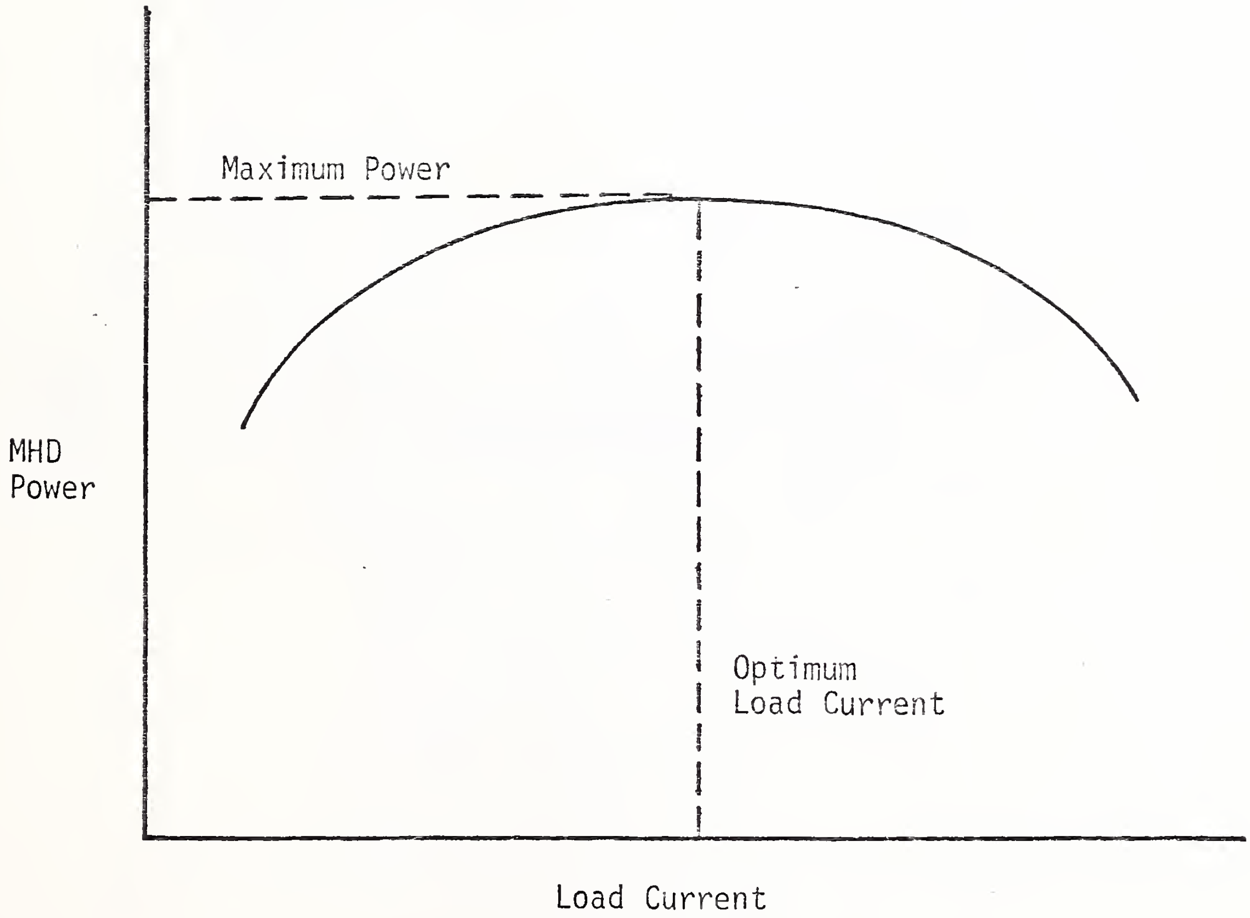


Figure 1. Optimization for Maximum Power

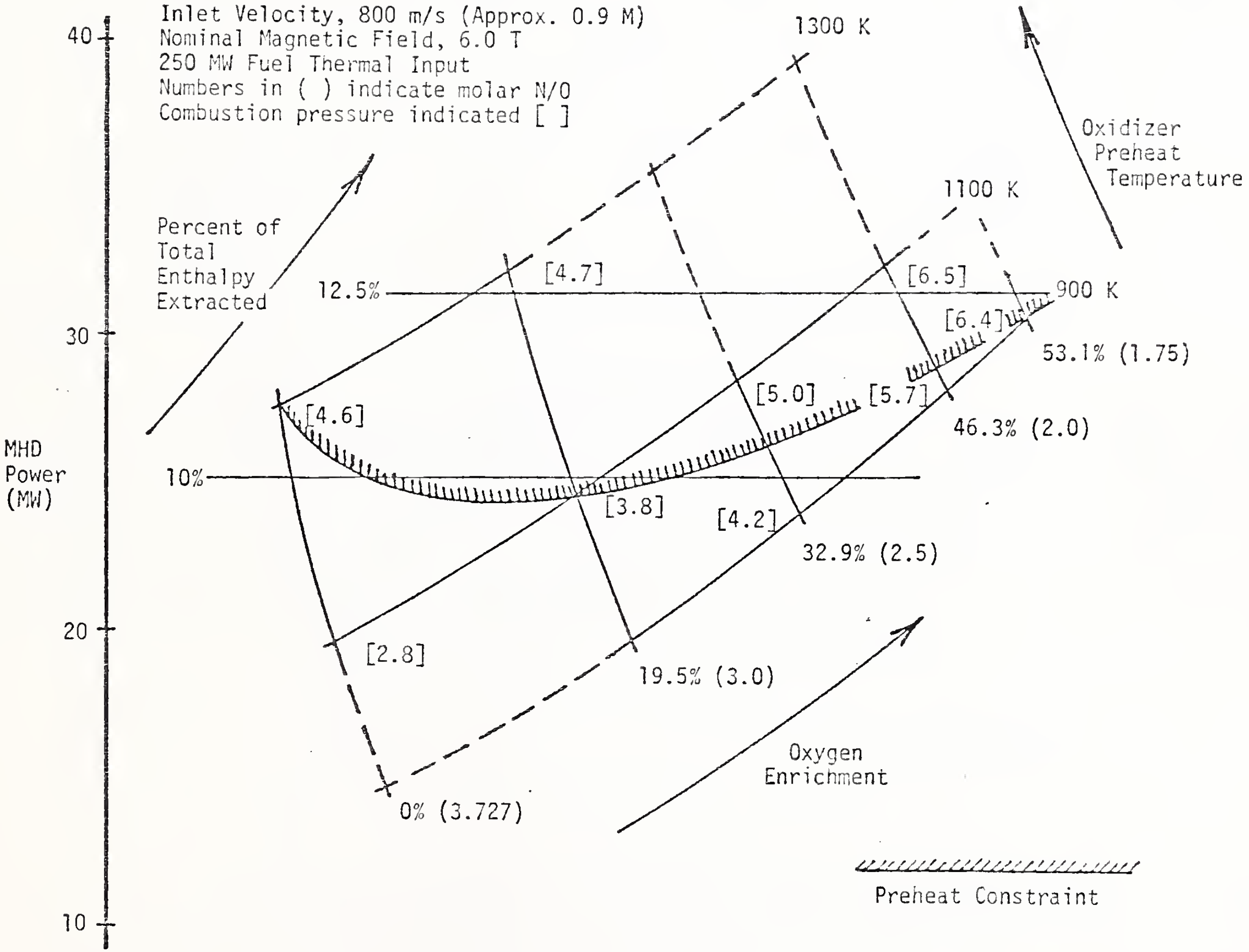


Figure 2. MHD Subsonic Design Power Performance Map

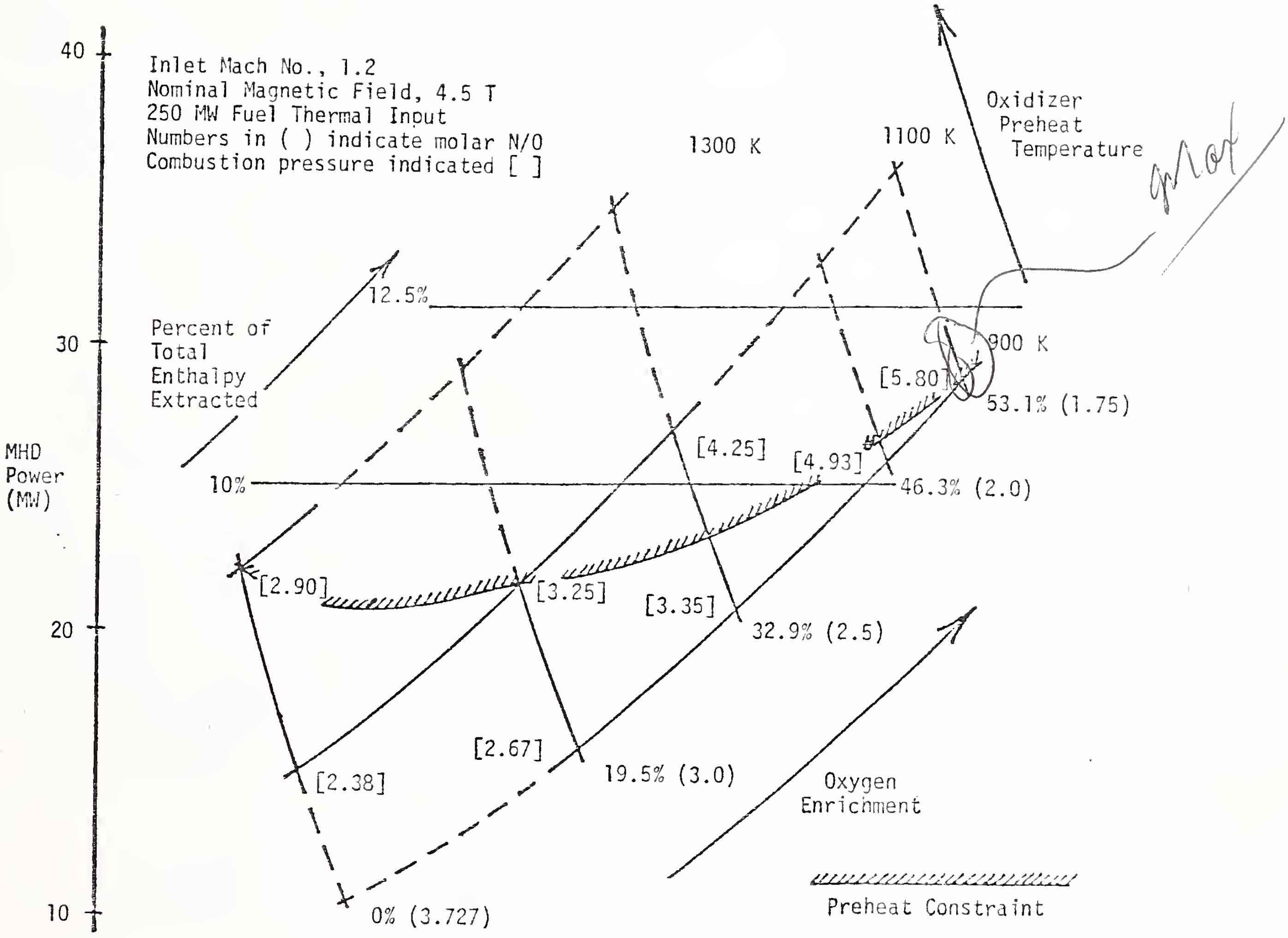


Figure 3. MHD Supersonic Design Power Performance Map

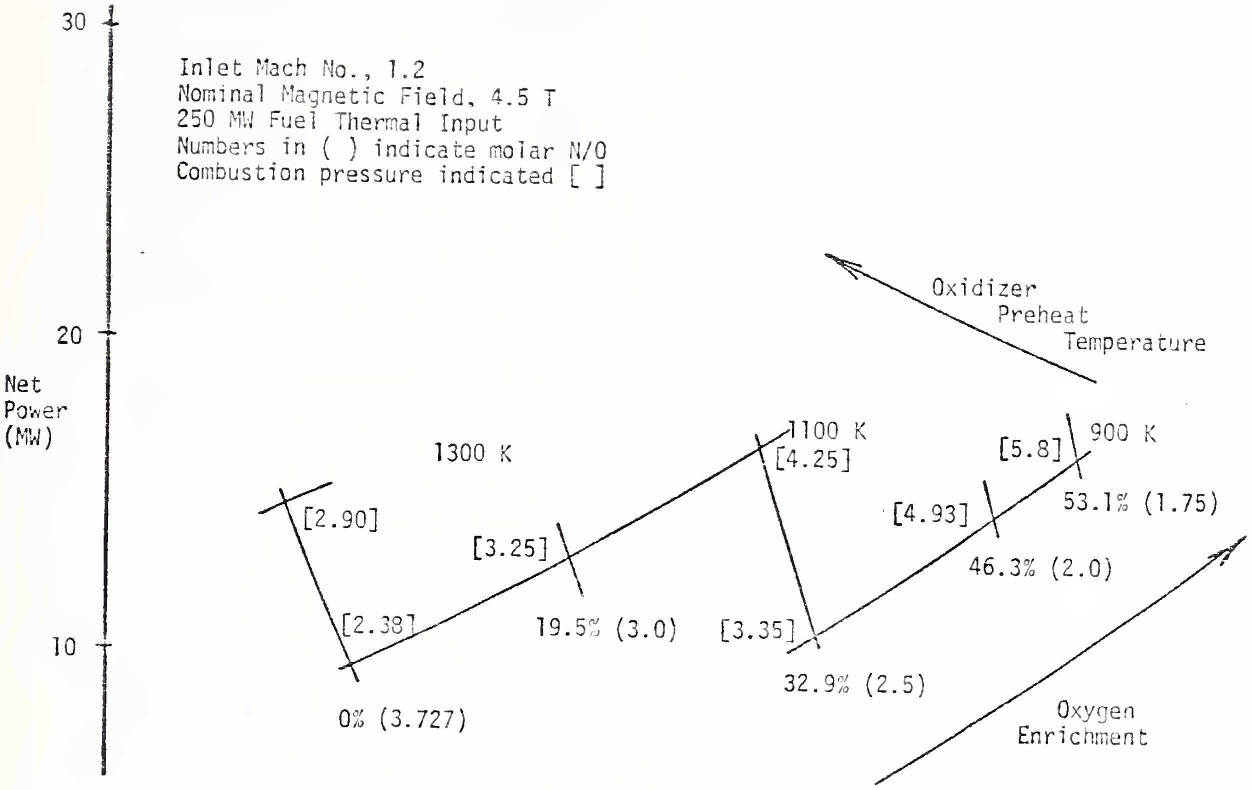


Figure 4. MHD Net Power For Supersonic Cases

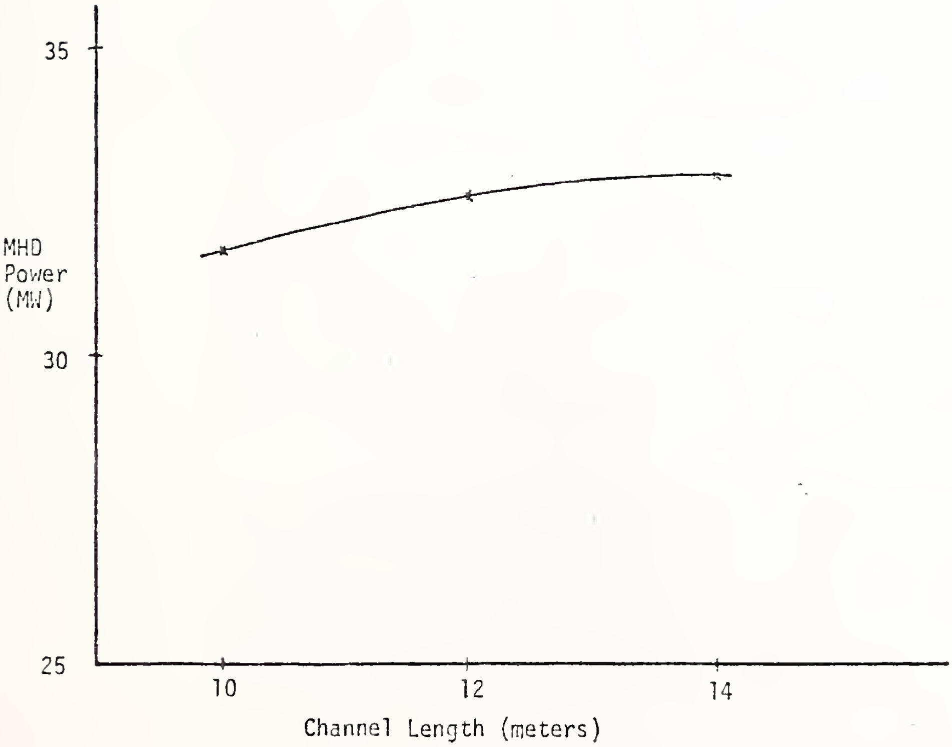


Figure 5. Effect of MHD Channel Length

3.0 HRSR PRELIMINARY DESIGN AND ANALYSIS

The following subsections describe the progress to date in the preliminary design and analysis of the heat recovery, seed recovery boiler (HRSR).

3.1 Design Philosophy and Physical Description

The HRSR boiler is still in a very early stage of system definition. Subsequent analysis will almost certainly result in some changes. Therefore, the following physical description, and to some extent the design philosophy, reflects the state of the design at the time of this writing, and should not be interpreted as the final word.

The physical layout of the HRSR boiler is shown in Figure 6. The lower furnace is sized to allow a little over two seconds retention time for the MHD exhaust gas, to allow equilibration of NO_x[14]. The lower furnace walls are evaporative waterwalls, studded for refractory retention. The refractory thickness is adjusted to keep heat transfer low, such that the gas exiting the lower furnace will be no cooler than about 2900°F, again for NO_x equilibration.

The upper furnace design departs somewhat from conventional design concepts, the idea behind it being to quickly dilute the gas through the wet slag regime, while minimizing the contract of wet

ash particles with solid walls. The bulk of the potassium sulfate condenses out in the temperature range from 2900°F to 1900°F[2], thus cool flue gas is recirculated in sufficient quantity to dilute the flow to 1800°F at the upper furnace exit. Secondary air is also introduced in the upper furnace to bring the overall stoicheometry to 1.05. The secondary air and tempering gas are introduced through slots normal to the flow and across the upper furnace roof and arch. The purpose of this is to create a protective boundary layer of tempering gas over the roof and arch. This protective gas layer will keep the wet ash particles off the surfaces and retard upper furnace clinker formation. The contour and injection distribution of the slotted roof and arch are designed such that the tempering gas will become reasonably uniformly mixed with the core flow at the furnace exit. An additional constraint on the roof contour is that it must introduce normal pressure gradients in the flow appropriately contoured such that separation on the arch is prevented. The secondary air is not uniformly mixed with the tempering gas but is injected from the most upstream slots. This will facilitate secondary combustion before the main flow is cooled too much to support the combustion.

While the upper furnace is unusual, its aerodynamic design is well within the state-of-the-art in turbulent mixing theory. The key is to keep the flow as two-dimensional as possible. The main source of three-dimensional effects is the double vortex set up in the furnace by the entering MHD flue gas jet at the bottom. The effect of those vortices may be approximately offset by opening the

injection slots wider along the furnace center plane. Unlike conventional boilers, this boiler will utilize considerable gas recirculation at its nominal operating condition. The irreversibility penalty is felt to be a worthwhile trade-off to avoid hard clinker formation. Subsequent analysis may show the efficiency loss due to such massive recirculation to be unacceptable. In this case the design will be modified to a more conventional, heavy slagging furnace top. This will involve much more soot blowing in the furnace and the initial slaging stages of the convective pass.

With the recirculating gas design, it will be difficult to maintain proper upper furnace operation for significantly off-design operation. Also, since supersonic MHD channel efficiency drops off quickly for off-design conditions, it is recommended that the MHD system be operated always near design. Thus, load variations will be absorbed by the existing Corette boiler.

Large, irregular shapes are expensive to build. However, since the furnace roof is not a waterwall, it need be no more expensive to erect than a conventional boiler roof. It will require more maintenance than a conventional design, and thus it should be designed from the outset for convenient maintenance. Figure 7 illustrates a workable concept for the structural design of the upper furnace roof, while Figure 8 illustrates the hinged doors which make up the upper furnace surface.

Figure 6 may include tubing parallel to the injection slots in the furnace roof. This is an optional feature and may be included or not, with little effect on the flow pattern in the upper furnace. The tubing constitutes a high temperature radiant metalic oxidant heater. The foregoing comments on cost do not apply to it. Made of 601 stainless, it would be expensive. It would, however reduce considerably the oxygen requirement to operate the plant. The heater is illustrated in Figure 9. The metal temperature is determined by a rather complex balance between radiant heat flux from the hot gas, reradiation from the refractory coated roof, convection from the refractory, and convection to the cooling gas and oxidant. Maximum attainable oxidant temperature would be about 1800°F. Significant development problems may surface with the radiant oxidant heater, and so for now it is recommended that the upper furnace be designed with provision for later installation of a full size high temperature air heater. More refined design calculations may justify the experimental installation of a small heater section.

The convective pass of the boiler is conventional in design. It does include more than the usual number of soot blowers. Also, it provides for control of the balance between intermediate temperature oxidant preheat and steam reheat and superheat. This is accomplished by splitting the gas flow into two parallel back passes[1]. Gas flow balance is provided by adjustable dampers at the cool end.

The approximate physical size of the HRSR boiler as shown in Figure 6 is as follows:

Lower Furnace: 28 x 28 x 51 feet
Upper Furnace: 28 x 28 x 10 feet
Convective Pass: 28 x 20 x 50 feet
Lower Steam Leg: 13 x 8 x 30 feet
Lower Air Leg: 13 x 8 x 30 feet

These figures are subject to change as the performance analysis proceeds.

3.2 Heat and Mass Balance

The preceeding section describing the HRSR boiler is based on hand calculations, and is undergoing constant revision as the results of the detailed heat and mass balance of the boiler become available. Several computer codes were available for performing the heat and mass balance (16,17,18). Of these, all are quite adequate for performing the turbine cycle analysis. The only one, however, which includes a reasonably detailed and versatile boiler model is PEPSI (TM) (Performance Evaluations of Power System Efficiencies).

PEPSI (TM) is a propriatary code developed by Energy Incorporated (EI), of Idaho Falls, Idaho. For this study, arrangements were made for PEPSI (TM) to be used on a time-sharing basis with

University Computing Systems (UCC) of Dallas, Texas, on a large mainframe computer operated by UCC.

While the PEPSI (TM) code is the best available for the present application, it turns out that it suffers from several significant deficiencies for the simulation of MHD HRSR boilers. These deficiencies are as follows:

a. The inability to simulate a radiant furnace in the heat recovery mode

b. The inability to simulate a fuel-rich combustion gas, or to account for oxygen enrichment

c. The inability to simulate flue gas recirculation

d. The inability to simulate a plit flue gas flow

e. The inability to simulate air heaters in pendent or horizontal air-in-tube configurations

Since the PEPSI (TM) code is propriatary, it was not economically feasible to obtain the source code to make the necessary modifications to generalize the code to account for the above effects. However, it appears that there are ways to modify the code inputs, and break up the steam cycle, such that a reasonably adequate simulation can be achieved.

In order to describe the methods being used to simulate the boiler steam cycle with PEPSI (TM), it is necessary to consider first the overall steaming order of the boiler. This is illustrated in Figure 10. The dashed lines in Figure 10 illustrate the way in which the cycle is broken up in order that PEPSI (TM) can simulate the dividing of the flue gas flow. Each section deliniated by the dashed lines in Figure 11 is simulated by a different run, with its own complete description in terms of the standard PEPSI (TM) inputs. These three separate models are illustrated in Figures 11 through 13. In the boxes delineating different stages, the upper right number gives the steaming order, the upper left number gives the flue gas order, and the lower right number gives the type of stage being modeled[5]. The types of stages that PEPSI (TM) is capable of modeling are as follows[5]:

1. Convective Superheater
2. Convective Evaporator
3. Convective Economizer
4. Convective Reheater
5. Convective Tube and Shell Air Heater (Flue gas inside tubing)

-1. Radiant Superheater
-2. Radiant Evaporator
-3. Radiant Economizer
-4. Radiant Reheater
-5. Convective Rotary regenerative Air Heater

This method of breaking up the cycle necessitates three runs to simulate one design iteration of the complete cycle, but it does alleviate (d) in the foregoing list of deficiencies.

Deficiencies (a) and (b) of PEPSI (TM), the inability to simulate a radiant furnace unless combustion is actually taking place in the furnace, and the inability to simulate a fuel-rich combustion gas, are being sidestepped by introducing both the primary and secondary air to the lower furnace. Thus, the overall stoicheometry is duplicated properly downstream of the upper furnace. This will yield somewhat erroneous results in the lower furnace, and to a lesser degree in the upper furnace. The error, however, is such that the code will overpredict the radiant heat flux if left to calculate that heat flux itself. The code does, however, provide for user input of either a radiant heat flux or a fouling factor, either of which can be used to manually correct the error introduced by allowing air-rich combustion to occur in the furnace. The inability to account for depleted nitrogen in the flow (oxygen enrichment) is not felt to be a significant source of error as long as the volume flow rate is properly input by using excess air in proper combination with fictitious energy losses. The fictitious energy losses can be input in the radiant furnace through the use of an unaccounted losses factor. This is also the mechanism used to simulate flue gas recirculation, item (c) in the list of deficiencies.

The inability to simulate air heaters in pendent or horizontal air-in-tube configurations, item (e), is circumvented by using fictitious reheater flows to replace the air heaters. The effects of these stages on the flue gas is identical to what air heater stages would be, and the fictitious reheat steam flows can be fairly simply related to the actual air flows by hand.

A great deal of space has been devoted to describing the deficiencies of the PEPSI (TM) code for the present application. In all fairness, it should be pointed out that the code does a great many things quite well. It is the best code we could find for the purpose. Energy Incorporated is presently in the process of completely rewriting the boiler portions of PEPSI (TM), such that all or most of the deficiencies listed herein will be corrected. Unfortunately, the new code won't be available until the summer of 1983. A copy of this section of this progress report is being supplied to EI in hopes they will insure the deficiencies are corrected so that we can use PEPSI (TM) in a much more straightforward manner for future MHD HRSR design work.

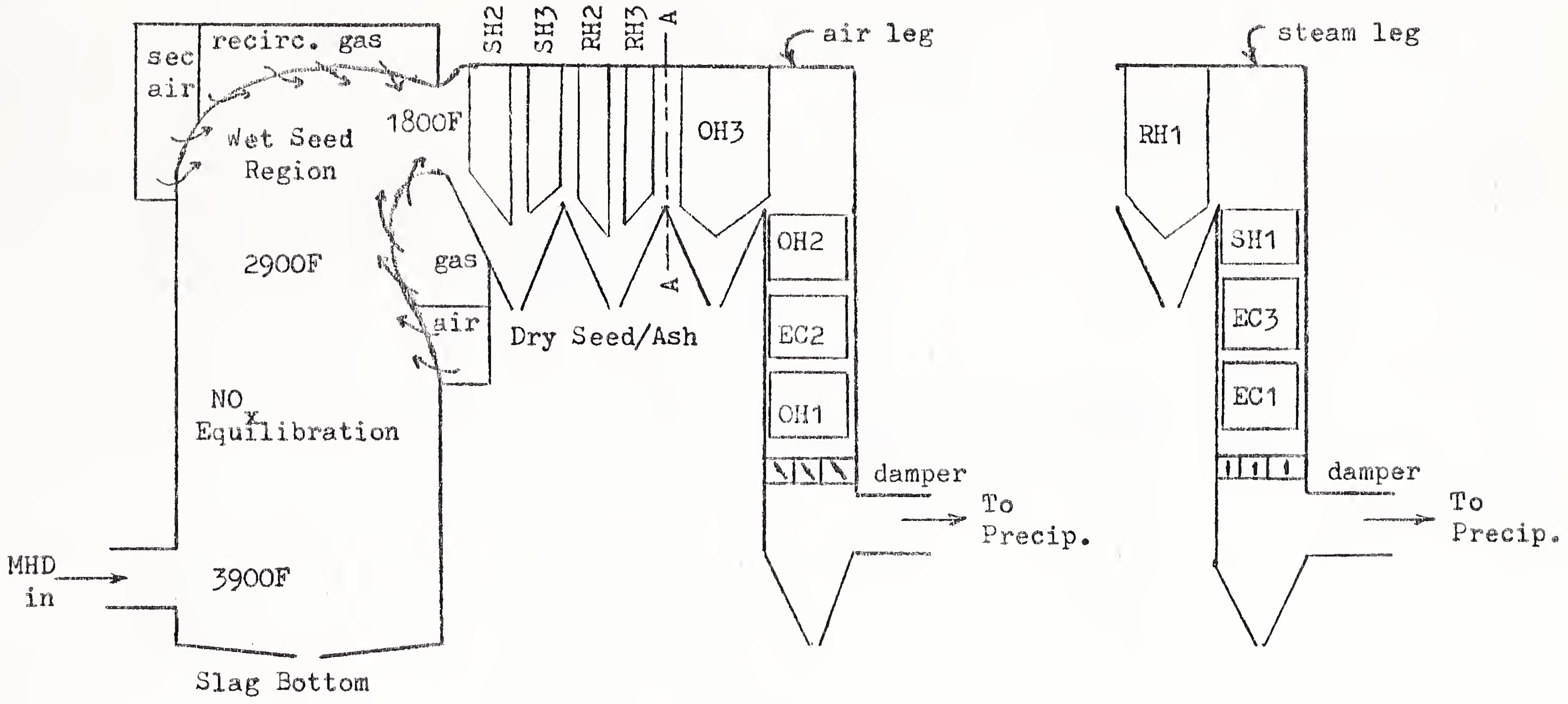
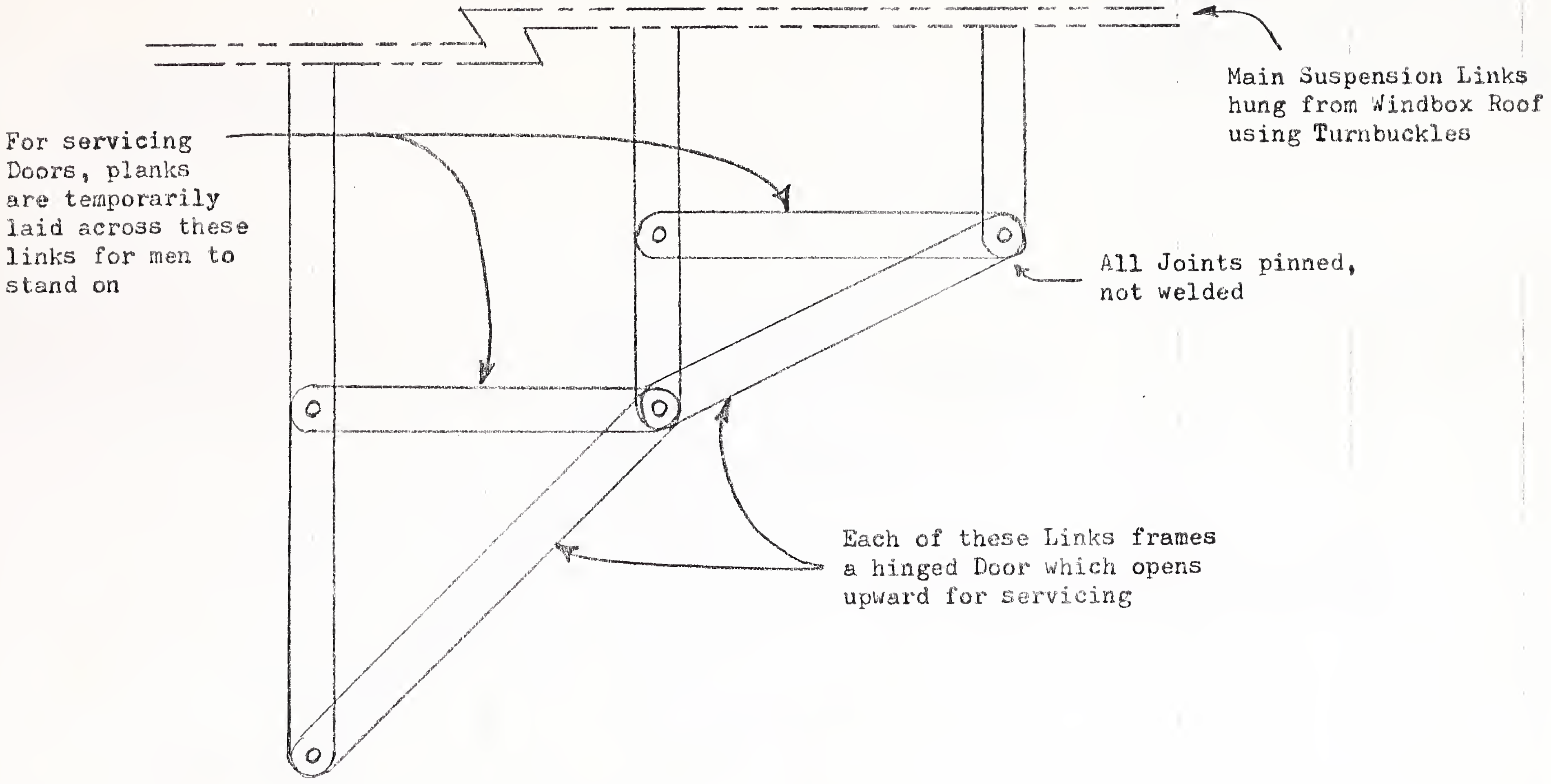


Figure 6. MHD HRSR Boiler Profile. Flue gas flow divides at Section A-A.



Main Suspension Links hung from Windbox Roof using Turnbuckles
For servicing Doors, planks are temporarily laid across these links for men to stand on
All Joints pinned, not welded
Each of these Links frames a hinged Door which opens upward for servicing

Figure 7. Structural Support for Slotted Upper Furnace Roof.

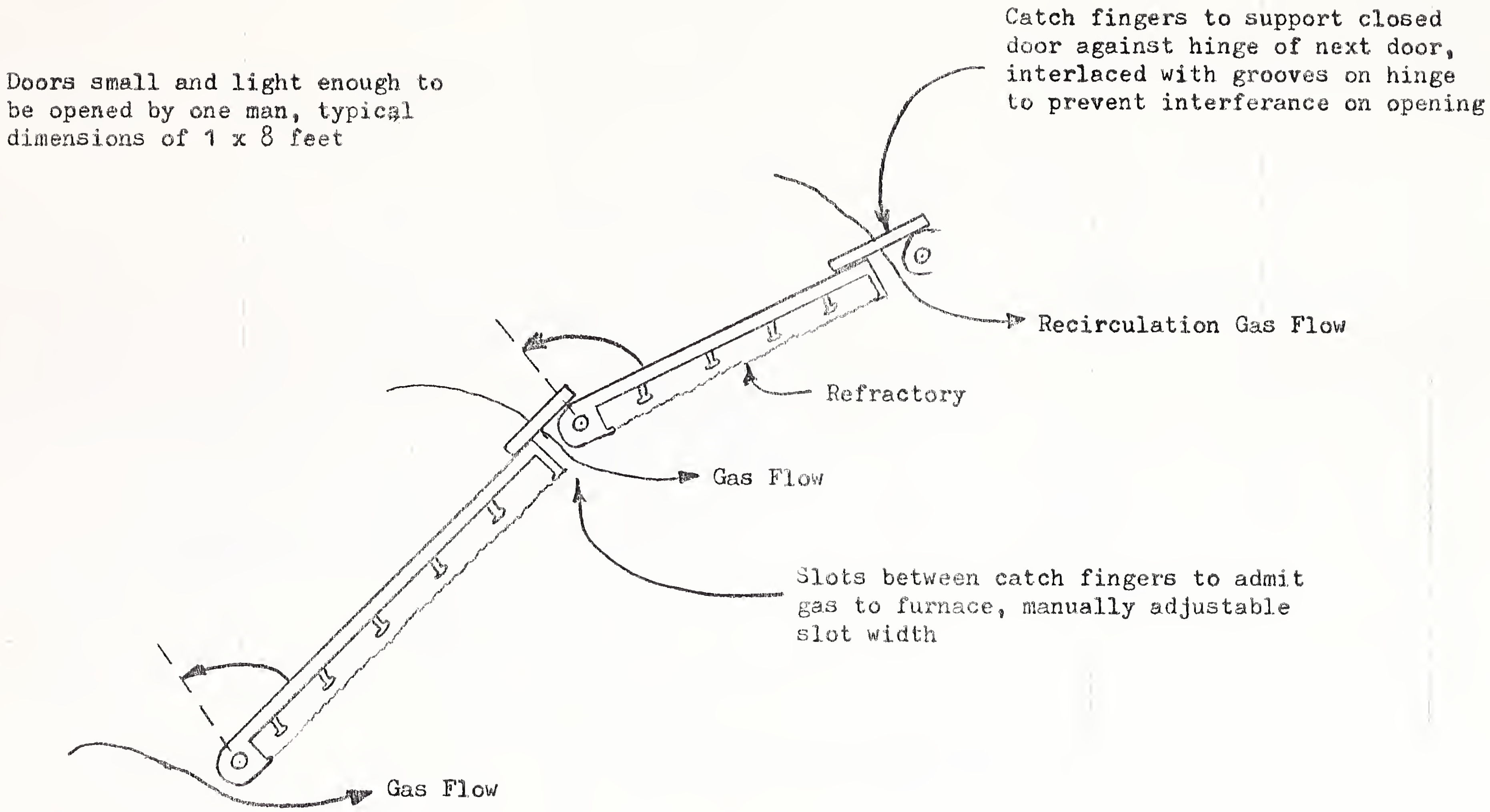

Doors small and light enough to be opened by one man, typical dimensions of 1 x 8 feet
Catch fingers to support closed door against hinge of next door, interlaced with grooves on hinge to prevent interferance on opening
Recirculation Gas Flow
Refractory
Gas Flow
Slots between catch fingers to admit gas to furnace, manually adjustable slot width
Gas Flow

Figure 8. Doors forming Upper Furnace Roof.

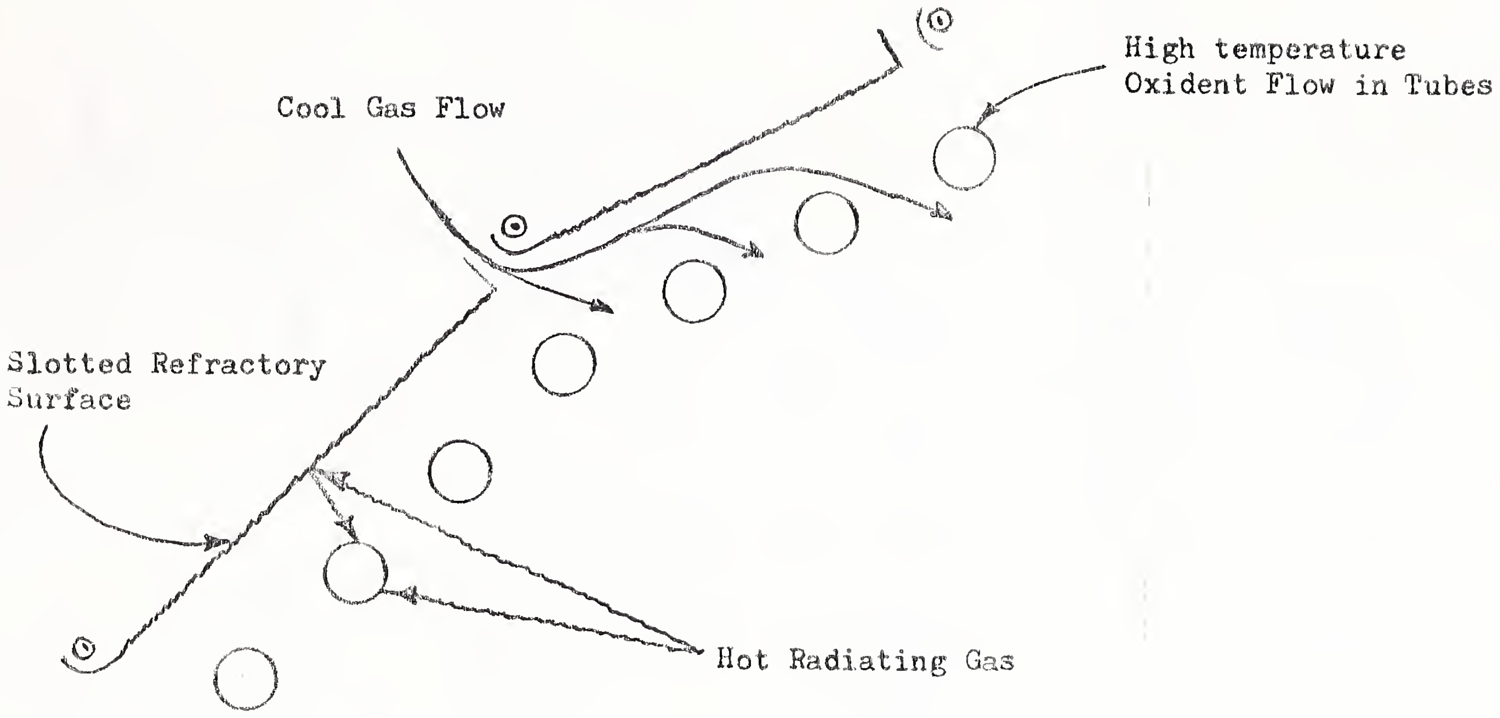


Figure 9. High Temperature Radient Metalic Oxident or Steam Heater in top of Radient Furnace.

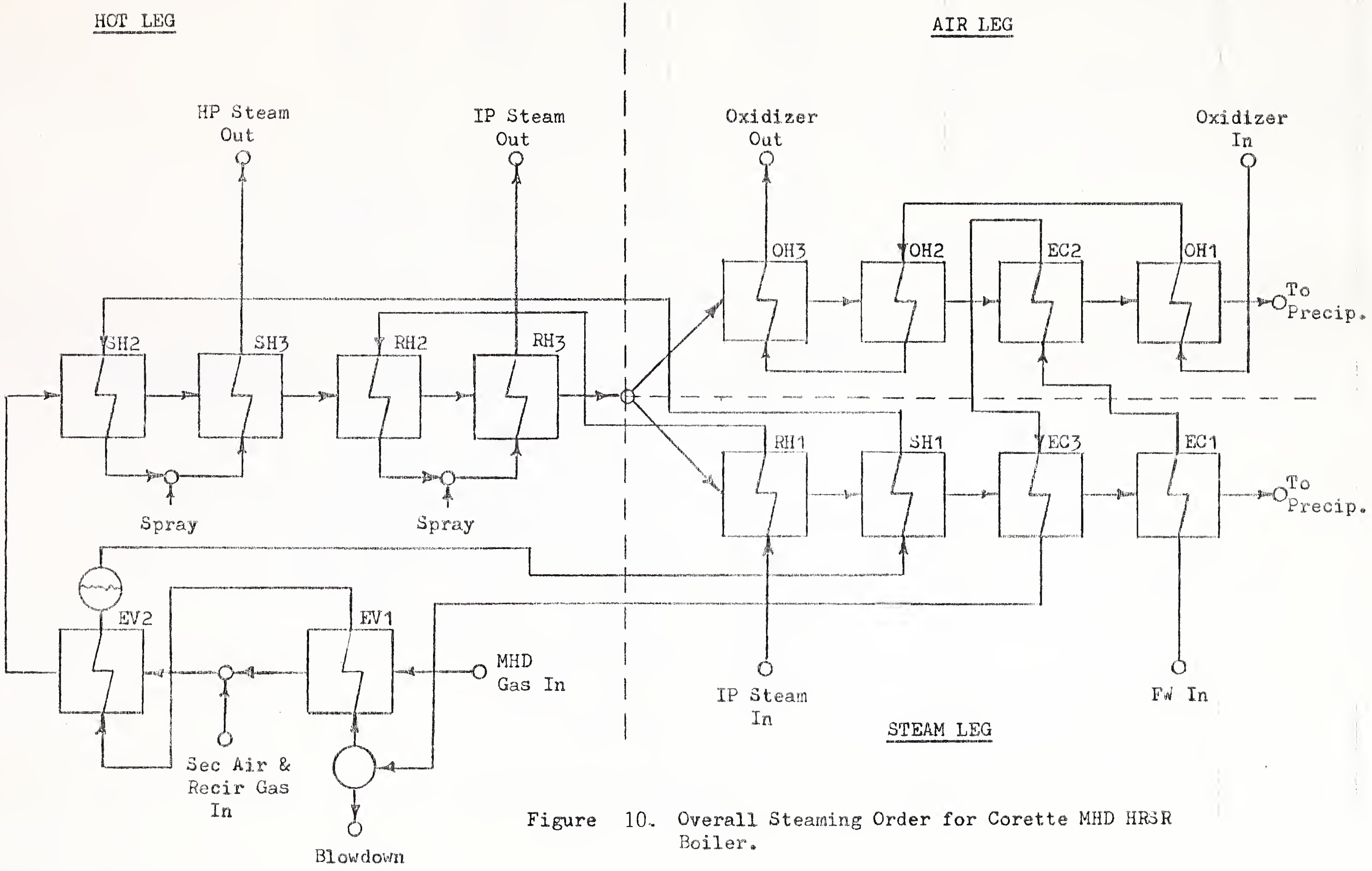


Figure 10. Overall Steaming Order for Corette MHD HRSR Boiler.

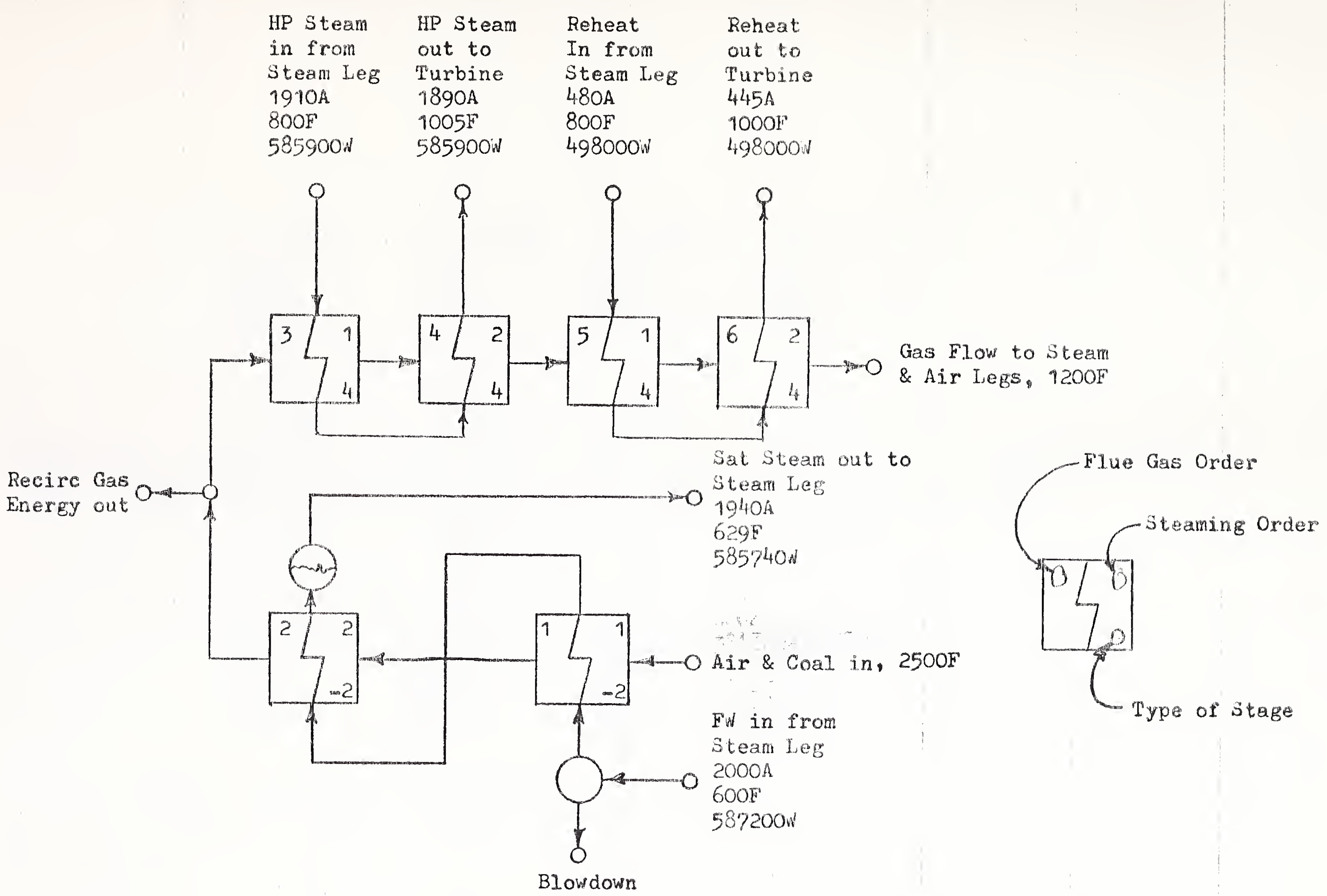


Figure 11. Hot Leg PEPSI(TM) Representation.

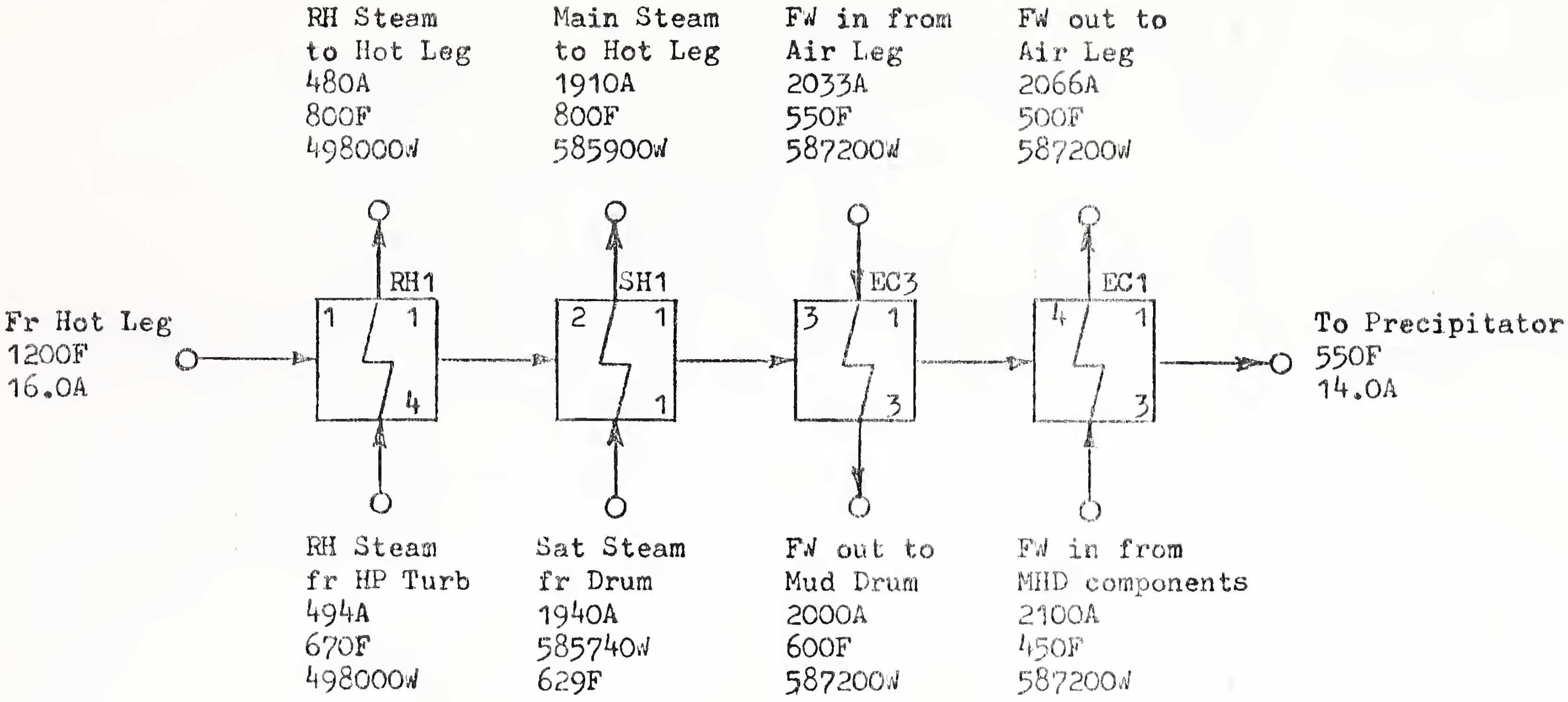


Figure 12. Steam Leg PEPSI(TM) Representation.

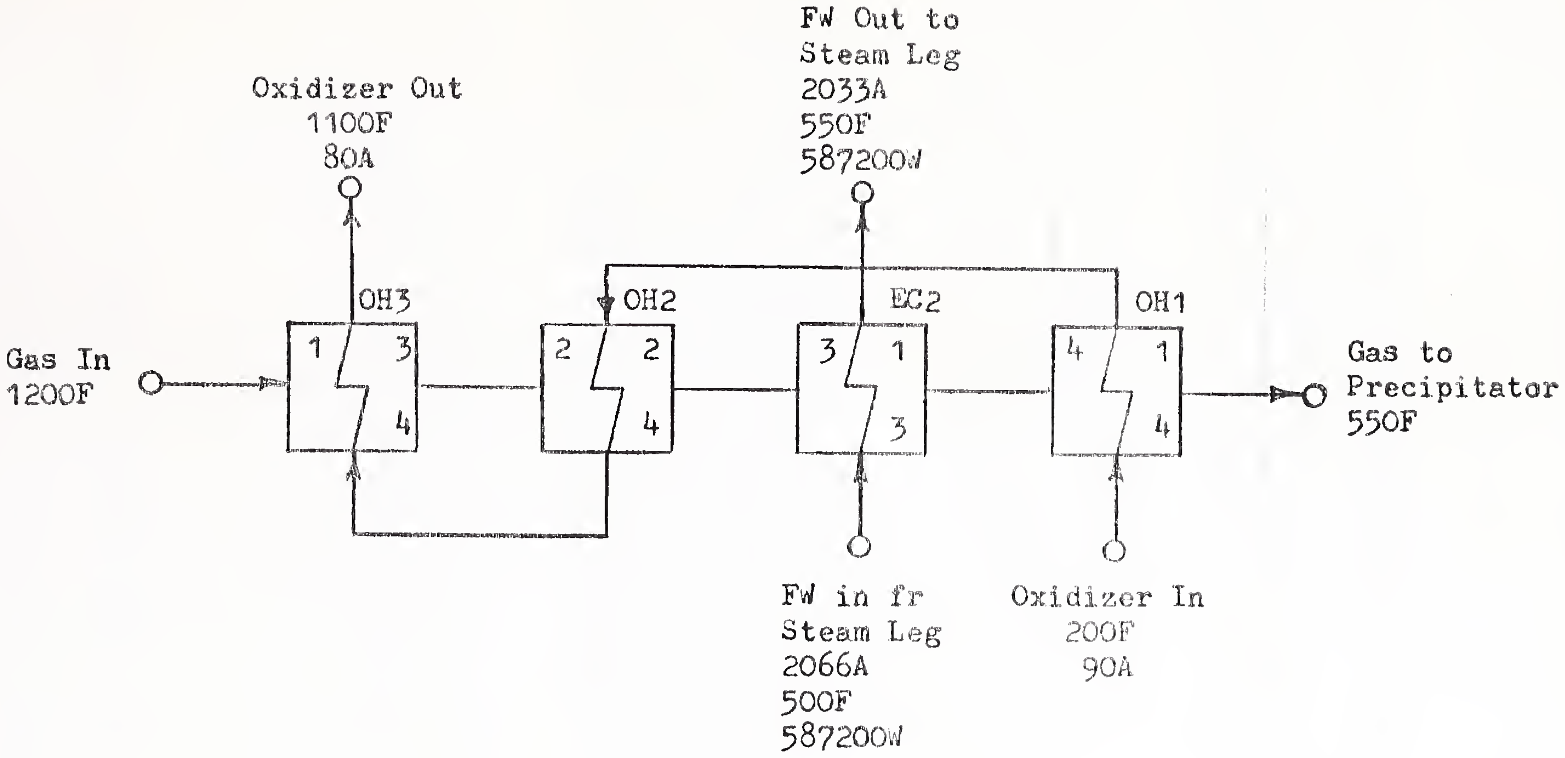


Figure 13. Air Leg PEPSI(TM) Representation.

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18. "PEPSI (TM) Manual, Volume I, User Input Description", by W. C. Kettenacker, P. H. Klink, G. L. Minner, Energy Incorporated, Idaho Falls, ID, last revision May 1, 1982.

ITEM NO	PART OR IDENT. NO	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR VENDOR	NO REQ'D

LEGEND

—/—/— FLUE GAS
- - - - - STEAM
——— CONDENSATE OR FEEDWATER
—X—X— OXYGEN ENRICHED AIR OR ASU PRODUCT GAS
— - — AIR
—o—o— COAL
P PRESSURE, PSIA
F TEMPERATURE, DEG. F
H ENTHALPY, BTU/LBM
W MASS FLOW RATE, LBM/HR.

NOTES:

(1.) DESIGN POINT PARAMETERS:
36 MOLE PCT. O_2 IN OXIDANT
10.0 METER ACTIVE CHANNEL LENGTH
FT. ALTITUDE
1160 DEG. F OXIDANT PREHEAT
SPECIFIC ENERGY CONSUMPTION OF AIR
SEP. UNIT: 178 KW HR. PER TEPO
(TON OF EQUIV. PURE OXYGEN)
5% THERMAL LOSSES THROUGH COMBUSTOR WALLS

(2.) THERMAL INPUTS:
CORETTE SIDE: 234.1 MWT
ROSEBUD COAL
23.8% MOIST. (AS REC'D)

MHD UNIT: 250 MWT
ROSEBUD COAL
5 % MOIST

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MATERIAL.

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DRAWN BY:	1/4/83
CHECKED BY:	
DESIGNED BY:	
PROJ. ENGR	
ENGR. MGR.	

U.S. DEPARTMENT OF ENERGY
COMPONENT DEVELOPMENT & INTEGRATION FACILITY
BUTTE PROJECT OFFICE MHD/10 BUTTE, MONTANA

MOUNTAIN STATES ENERGY INC.
P.O. BOX 3767 (406) 494-7100
BUTTE, MONTANA FTS 587-7100
DOE CONTRACT AC07-78-10-01946

TITLE: ADVANCED TEST SYSTEM, CORETTE RETROFIT SCHEMATIC

SIZE D
DWG NO. D02-DNKC-001
REV. A
SCALE: NONE
SHEET 1 OF 1

ITEM NO	PART OR IDENT NO	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR VENDOR	NO REQ'D

INFORMATION ONLY
DATE 3·2·83
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U.S. DEPARTMENT OF ENERGY
COMPONENT DEVELOPMENT & INTEGRATION FACILITY
BUTTE PROJECT OFFICE MHD/10 BUTTE, MONTANA

MOUNTAIN STATES ENERGY INC.
PO BOX 3767 (406) 494-7100
BUTTE, MONTANA FTS 587-7100
DOE CONTRACT AC07-78-ID-01945

TITLE [illegible] MHD [illegible]
BOILER

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SCALE [illegible] SHEET 1 OF [illegible]

PART OR IDENT. NO.	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR VENDOR	NO. REQ'D

ATTACHMENT #4

Mountain States Energy Inc.
POST OFFICE BOX 3767
BUTTE, MONTANA 59702
(406) 494-7100
FTS 587-7100

Date: February 8, 1983

To: E. W. Ashby

Thru:

Copies:

From: G. L. Nelson

Subject: Trip Report on Visit to Corette Power Plant, January 27, 1983

The purpose of this trip was to familiarize ourselves with the general layout of the Corette plant, and to understand some of the site-specific limitations of the proposed retrofit. It appears to me that space limitations will be a problem. The MHD power train will have to be located on the north side of the main plant. We discussed a number of questions with Lee Alt, plant manager, and Mike Hofacker, who worked there as an engineer for several years. Some of the important facts which emerged from these discussions were as follows:

a) The Corette plant has no excess capacity in the plant air supply system, the instrument air system, the waste treatment systems, or in the electric power system.

b) Although the plant is not now running near its maximum availability or capacity, this may change in 2-3 years when the new transmission line into Washington state is completed. This should enable MPC to sell excess power to west coast utilities.

c) The existing electrostatic precipitator will not be available to handle MHD flue gas.

Others who accompanied me were Don Cott, Bob Hiers of MSE, Gloyd Simmons and Neal Egan of Multitech, and Dr. Roy Johnson and Dr. Don Rudberg, both of Montana State University. In summary, I believe the trip was useful in that it allowed us to see the plant close up and also to discuss some of the operational problems with personnel who are familiar with the plant.

GLN:dlk

ATTACHMENT #5

During the course of this project, project reviews are solicited from participating utilities, members of the EEI Task Force and MHD consultants. Comments on the Project Milestone #2, MHD Retrofit Schematic and Baseline Specifications were received from the following:

- Savannah Electric and Power Company
- Montana Power Company
- Northern Indiana Public Service Company
- Public Service Company of New Mexico
- Commonwealth Edison
- Pudget Power
- Montana-Dakota Utilities Co.
- Gulf States Utilities Co.
- Allegheny Power System
- Southern California Edison Co. (2)
- Charles T. Main, Inc. (2)
- Mr. Finn Hals
- Mr. Stewart Way
- Electric Power Research Institute
- Mr. Roy Johnson
- Mr. Don Rudberg

Savannah Electric and Power Company P.O. Box 968, Savannah, Georgia 31402 (912) 232-7171

February 15, 1983

Mr. E. W. Ashby
Mountain States Energy, Inc.
Post Office Box 3662
Butte, Montana 59702

Dear Mr. Ashby:

Mr. W. C. Smith, Senior Vice President, Savannah Electric and Power Company, recently elected to take normal retirement. As a result, I have "inherited" a number of his files including the one concerning MHD.

I have no comments or recommendations to make at this time but would appreciate remaining on the project mailing list, with the possibility of future involvement.

Sincerely,

Frank E. Gabrels

Frank E. Gabrels
Director, System Evaluation

MONTANA POWER COMPANY MPC GENERAL OFFICES: 40 EAST BROADWAY, BUTTE, MONTANA 59701 • TELEPHONE 406/723-5421

February 4, 1983

Mr. E.W. Ashby
Mountain States Energy Inc.,
P.O. Box 3662
Butte, MT 59701

RE : Your letter dated January 17, 1983
83MSE-010

Dear Mr. Ashby:

The following comments are in response to your letter 83MSE-010 and its attachment "Specification of Baseline Design".

Before addressing specific areas of the letter, I believe some general comments on the philosophy of design for the Advanced Test System at the J.E. Corette plant are in order. Some of the comments in your cover letter and the attached design requirements are not the same as those defined in The Montana Power Company's report "MHD Advanced Test System Performance Requirements" for the Montana Department of Natural Resources and Conservation, contract # FS-MPC-042. I do not feel it is appropriate to change the criteria established by the utilities in this report. These criteria are qualitative in nature, but specific in the philosophies that the utility industry feels should be applied to the design of the Advanced Test System to show MHD's viability. These requirements also provide for performance standards that can be met at less cost and less risk than some of the design requirements you are suggesting. I would recommend a matrix of the utility requirements be established and all points addressed. An overlay matrix of technical or demonstration requirements could also be prepared and where conflicts occur, the hierarchy requirement can be identified and justified. Of course, this is keeping in mind 1) the goal is to make MHD work and 2) costs should be kept to a minimum.

In paragraph 3 of your cover letter, you ask about the amount of oxygen enrichment and the amount of air preheat required. We consider these as technology requirements and thus parameters that the MHD scientific community must provide. However, the utility's evaluations, as stated in the report, indicate that the ATS should use oxygen enrichment. The use of air preheaters instead, would have to be substantially justified and documented to have them accept this mode of operation. Similarly, the size of the topping unit should be based on scaling factors established from your MHD test data and excessive risk should be avoided. The utility philosophy for sizing is stated on page 9, Appendix I of the above referenced report.

In the "Specification of Baseline Design", you state that it is critical to improve overall plant efficiency. I must emphasize that this is not a criteria of the utility industry nor is it a requirement of The Montana Power Company. I would like to quote the first paragraph, page 3, Attachment I of the referenced report.

> "The main emphasis of the Advanced Test System is not to achieve performance goals expected from a commercial facility, but rather to provide sound evidence that can be used as a basis for reliable prediction that a first generation commercial power plant using the technology could be competitive with conventional electric energy generating technologies."

Other statements in the report elaborate on this theme. Needless to say, a secondary goal would be to demonstrate, at as high an efficiency as possible within your confidence limits, that MHD will work. A higher overall plant efficiency, though desirable, is not required. I, therefore, believe your requirements #1 and #4 are not appropriate. Requirement 3 is essentially a restatement of the utility position, and requirement 2 is in general agreement with the utility report. Seed reprocessing was of concern to many of the utilities, but not specified in the report. Therefore, your statement "demonstrating some degree of seed recovery and reprocessing", is appropriate.

We are in agreement with the bulk of the rest of the report, except for the previously discussed air preheaters. Specific plant-related comments have been exchanged at our techincal meetings, so I will not repeat them here. We are in agreement with the concepts as presented in your working drawing.

If you have any questions, please call me at 723-5421, extension 2585.

Very truly yours,

Fred E. Walter
F.E. Walter
Senior Engineer Specialist

FEW/sv/E:6

NIPSCO

Northern Indiana Public Service Company

Plant Engineering & Construction
591 Marquette Mall Office
450 St. John Road
Michigan City, IN 46360

February 7, 1983

Mr. E. W. Ashby
Mountain States Energy, Inc.
P.O. Box 3662
Butte, Montana 59702

Dear Mr. Ashby:

In response to your January 17, 1983, letter to Mr. H. P. Lyle, we have reviewed the "Specification of Baseline Design" and schematic D01-01AM-016. We have no comments at this time.

Please keep us advised of your progress on this important project.

Very truly yours,

William R. Elliott
Manager, Plant Engineering
and Construction

VMA:ve

PNM PUBLIC SERVICE COMPANY OF NEW MEXICO
ALVARADO SQUARE ALBUQUERQUE, NEW MEXICO 87158

February 2, 1983

Mr. E. W. Ashby
Mountain States Energy Inc.
Post Office Box 3662
Butte, MT 59702

Dear Mr. Ashby:

Subject: Review of Baseline
Design Specification

Members of the Resource Analysis Section have reviewed the information received from you under cover of your letter dated January 17, 1983. At the level of detail contained therein we have no comments. However, as the design work proceeds we are very interested in the design of the air emission control equipment and would like to receive as much detail on this aspect as possible.

Due to increased work loads in other areas, I have been unable to support the Edison Electric Instute (EEI) MHD Task Force. This has now been assigned to Mr. Stephen F. Anderson, Resource Appraisal and Fuel Conversion Group Leader of the Resource Analysis Section. Please forward any future material to Mr. Anderson.

Sincerely,

DJGroves/sfa

D. J. Groves
Supervisor, Resource Analysis Section

SFA:meg

cc: Mr. S. F. Anderson
Mr. A. L. Martinez

Commonwealth Edison
One First National Plaza, Chicago, Illinois
Address Reply to: Post Office Box 767
Chicago, Illinois 60690

February 3. 1983

Mr. E. W. Ashby
Mountain States Energy Inc.
P.O. Box 3662
Butte, Montana 59702

Dear Mr. Ashby:

I reviewed the information on the MHD test system and concur with the work done to date. My background is much stronger in the areas of planning and operations than in design, and thus I do not feel qualified to answer your specific questions. The general approach is good in that it minimizes the interfaces between the existing plant and the test system and thereby keeps the project as simple as possible. I feel that this simplicity is essential to a successful project because any failure of the system, whether or not it is related to the MHD facility, will be attributed to MHD. The impression created by a test of this type may be as important to the future of MHD as the actual test results.

Please let me know if you would like me to expand on any of these comments.

Sincerely,

R L Bolger

R. L. Bolger
Assistant Vice President

PUGET
POWER

MCGR-016-83

February 2, 1983

E. W. Ashby
Mountain States Energy, Inc.
Post Office Box 3662
Butte, Montana 59702

Dear Mr. Ashby:

I have reviewed your Specification of Baseline Design for the Advanced Test System Retrofit Study.

I have no comments or contributions to make. Without the referenced documents, it is not possible to make a meaningful review.

Very truly yours,

T. J. McGrath
Director
Generating Plant Engineering

TJM/bms

Puget Sound Power & Light Company Puget Power Building Bellevue, Washington 98009 (206) 454-6363

MONTANA-DAKOTA UTILITIES CO.

400 NORTH FOURTH STREET - BISMARCK, ND 58501 - TEL. (701) 222-7900

February 7, 1983

Mr. E. W. Ashby
Mountain States Energy, Inc.
P. O. Box 3662
Butte, MT 59702

Dear Mr. Ashby:

In response to your letter to Mr. Kroeber of January 17, we have not had the time to thoroughly study the base line design and schematic diagram you sent and therefore have no comment at this time. Our interest in the project continues and we request that you continue to keep us informed of its progress. Thank you.

Yours truly,

Earl F. Backhaus
Power Production Manager

EFB:fs

cc: Mr. W. W. Kroeber, General Office

GULF STATES UTILITIES COMPANY
POST OFFICE BOX 2951 • BEAUMONT, TEXAS 77704
AREA CODE 713 838 6631

January 28, 1983

Mr. E. W. Ashby
Mountain States Energy, Inc.
P.O. Box 3662
Butte, Montana 59702

Dear Mr. Ashby:

GSU appreciates the opportunity to comment on the work in developing a conceptual design of retrofitting an existing power plant with an MHD Advanced Test System. Although GSU has no direct involvement in the study of the MHD power cycle for electricity generation, we have experience in investigating means by which advanced technology can be integrated with an existing power plant unit. Our expertise is mainly in retrofitting existing power plants with coal gasification systems including oxygen extraction plants. I hope that our comments will assist your company in the remainder of your study of an MHD retrofit.

The primary concern in integrating a new cycle with an existing one is in the area of controls. The operational integrity of both the new and existing systems must be maintained. From the wording in the "Specification of Baseline Design" for the MHD retrofit, it is obvious that MSE is aware of the problem associated with integral control of all the components in the proposed cycle. Although we have no specific comments regarding control schemes, the most important aspect from a utility viewpoint is to ensure that an upset in either generating system (the MHD or existing cycle) should not result in the loss of both systems.

With respect to the amount of oxygen enrichment desired for the combustion air to the MHD cycle, if possible, no or minimal enrichment would be preferred. The "Baseline Design" indicates that in order to minimize the amount of oxygen enrichment large, high temperature air preheaters would be required to achieve combustor oxidant temperatures of 1800°F. Given a choice, it would be preferrable not to have an oxygen extraction plant included in a cycle that is attempting to prove the operating feasibility of a new technology. An economic and technical trade-off study should be performed comparing an on-site oxygen plant, purchased oxygen (pipeline or bulk), and using the high temperature air preheater.

A similar analysis was performed for a proposed medium BTU coal gas facility on GSU's system which indicated that due to the cost, availability, and reliability of a pipeline oxygen supply it was not feasible to build an oxygen plant.

My last comment relates to the location of the MHD cycle at the existing plant. Due to safety and economic concerns (e.g. steam line ruptures and heat loss) it is recommended that the MHD cycle be sited as close to the existing boiler as possible.

If you have any questions or would like to discuss these comments please contact me at (713)838-6631, extension 2226 or Mac Rogers at (713)838-6631, extension 2269.

Sincerely,

Roy J. West

Roy J. West
Manager, Special Programs

MBR/daw

cc: MHD file

HOMER T. McCARTHY
Director, Generation Planning

Allegheny Power System

Bulk Power Supply
Cabin Hill, Greensburg, PA 15601 (412) 838-6539

February 7, 1983

Mr. E. W. Ashby
Mountain States Energy, Inc.
P. O. Box 3662
Butte, MT 59702

Dear Mr. Ashby:

This is in reply to your letter of January 27, 1983, requesting comments on the MHD Advanced Test System project. We are not familiar enough with MHD technology to offer meaningful comments on the "Specification of Baseline Design" and the Corette Retrofit Schematic Drawing D01-01AM-016.

However, as you may know, Allegheny Power System was the host utility for the Rivesville Atmospheric Fluidized Bed Combustion (FBC) 30 MW_e demonstration unit. While this project had a number of problems, it did accomplish its stated purpose--it generated electric power with a FBC boiler. The experiences from Rivesville provided valuable information which has been incorporated in the TVA 20 MW pilot plant at Paducah, Kentucky. Interestingly enough, most of the problems at Paducah have been with conventional pulverized coal-fired power plant type equipment such as fan bearings, pump seals, etc.

The following general comments are based largely on our experience as a host utility at Rivesville:

1. Many of the problems at Rivesville were the result of the scaling factor. The boiler design was extrapolated from a laboratory bench model to a 30 MW unit.

2. The Rivesville FBC boiler was fitted into an existing boiler space in an existing plant. This severely limited the flexibility that could be built into it. I would recommend a stand-alone unit with ample provision for instrumentation, testing, and trying of alternate schemes.

3. The Rivesville FBC boiler produced steam for use in an existing turbine generator. There were long periods of time when the FBC boiler generated steam was of insufficient pressure, temperature, or quantity to be used in the plant turbine and had to be vented. The result was make-up problems for both the plant and the FBC boiler.

Allegheny Power System
Bulk Power Supply

4. The 20 MW FBC pilot plant at Paducah will not generate any power because the anticipated capacity factor (allowing for the test program needs) did not justify the cost of a turbine. Instead they are condensing the steam they generate. I would suggest that if a pilot plant is built and operated prior to construction of the Corette retrofit, the steam be either condensed or used in an existing standby turbine of appropriate size which could be powered solely by the MHD generated steam.

I believe many of the lessons learned at Rivesville could be applied to the development of any advanced generating technology and are not restricted to FBC or MHD. I hope these comments will be helpful.

We would appreciate it if you could send us any information you may have on the current status of MHD development.

If you have any additional questions on the Rivesville FBC project and associated problems, please contact R. L. Ballentine, Senior Engineer, Generation Planning, Phone (412) 838-6545.

Very truly yours,

Homer T. McCarthy

Homer T. McCarthy
Director
Generation Planning

cc: Mr. R. L. Ballentine

Southern California Edison Company

P. O. BOX 800
2244 WALNUT GROVE AVENUE
ROSEMEAD, CALIFORNIA 91770

January 14, 1983

Mr. J. M. Sherick, Vice President
Mountain States Energy, Inc.
P. O. Box 3662
Butte, Montana 59702

Dear Jack:

Subject: DNRC Retrofit Project

I discussed the plant selection and flow sheet with Gary Staats yesterday, and at his suggestion I am sending my comments on to you.

Basically Jack, the Corette Plant is too big. I have the impression that the plan is to run the MHD portion (at about 25% of the total existing unit steam flow) in parallel with the existing boiler. The two steam generators will not be identical but must balance main steam and reheat steam flow in the proper ratio. My opinion is that this is impossible without a very complex and expensive computer controlled steam flow system. This, I submit, is not the goal of the project; the goal is to demonstrate MHD not fancy steam flow systems.

This retrofit will only succeed on this plant if it is operated on MHD steam only, at whatever partial turbine output results.

There are some requirements in the "Retrofit Design Options" under the combustor heading "heat losses: 4-5% for reasonable overall efficiency." Specific efficiencies are also spelled out for the channel and heat recovery seed recovery unit. I had hoped that the role of efficiency in the first demonstration unit had been clearly understood by now. But I will repeat it nevertheless - efficiency is not the goal and there is no basis for preselecting component efficiencies. As long as the existing plant efficiency is approached, the only valid goal is to make the plant work!

There was mention of separately fired air heaters in the "Retrofit Design Options," but I was glad not to see

any on the flow sheet Gary left me. MHD is being touted as being environmentally acceptable. If true, then any separately fired heaters would have to include appropriate clean-up, and the result is an even larger and more complicated plant. For this first plant, an air separation unit is the way to go.

Gary and I talked about seed recovery, and there seems to be some consideration for using non-regenerated seed. I hope this gets thoroughly thought through before any decisions are made. Remember the goal - the plant must work. It seems to me, therefore, that the first plant should use Potassium Carbonate as seed, collect the spent seed and demonstrate or solve the regeneration process separately. Anything else is unproven and jeopardizes the achievement of the goal.

I cannot emphasize the goal enough. If the plant fails, or even sputters, because of complex steam flow control systems, or other non-MHD reasons, MHD will be seen as a failure. The funders of the program are not technical people and will not make any MHD/non-MHD distinction. The program at this point is too fragile to have anything other than an MHD plant that works!

I hope these comments will cause some redirection in the project. My intent is only to maximize the probability of success; and if there is anything I can do along this line to help, please do not hesitate to call me.

Sincerely yours,

Jim

James W. Griswold

cc: Fred Walter, Montana Power Co.
J. D. Leeper

Southern California Edison Company

P O BOX 800
2244 WALNUT GROVE AVENUE
ROSEMEAD, CALIFORNIA 91770

January 26, 1983

Mr. E. W. Ashby
Mountain State Energy
P. O. Box 3662
Butte, Montana 59702

Dear Mr. Ashby:

This letter is in response to your request of January 17, 1983 for comments on the MHD Retrofit Schematic and Baseline Specification. I had a discussion with Gary Staats on the plant selection and the schematic on January 13. As a result I sent some general comments to Jack Sherick, and I have enclosed a copy of that letter for your use. The following is mainly directed to the Baseline Specification.

The second paragraph of the introduction states "achieving the improved...efficiencies...which are attainable from MHD." This then leads to the first specification requirement of 17-20% enthalpy extraction by the channel. I would like to refer you to your Ref. 2 (Montana DNRC Project), Appendix 1, page 3, and also my letter to Jack. I cannot emphasize too strongly that efficiency is not the goal, and the DNRC report (your Ref. 2) echoes that. Further, there is no implication in that report that a specific channel enthalpy is desired, but it seems to me that the Baseline Specification implies that there is. See also Appendix 1, page 5, for the efficiency requirements.

The second requirement includes "...demonstrating some degree of seed...reprocessing." There is also a mysterious box on the schematic called "seed processor." I don't know what all this means, but it's my opinion that the ATS be as simple as possible (see your Ref. 2, Appendix 1, page 7) and that the seed be Potassium Carbonate and any reprocessing be done separately. The ATS is not the place to try new or untried approaches.

The third requirement is a proper statement of the goal of the ATS. I feel, however, that the other parts of the specification are not in keeping with that goal. The

fourth requirement "same or greater overall plant efficiency" is also a realistic goal; but earlier statements in the specification contradict this goal.

In order to meet the Performance Requirements, it is not necessary to compromise the design of the MHD unit, nor, if the plant to be retrofitted is properly selected and/or operated, is one "...forced to fire the existing boiler...." In fact, I do not believe it is possible to fire two different steam generators in parallel without a complicated control system. Such a system, although feasible, is not in keeping with the project goals.

The specification statement "...the required scale-up of MHD components would be too large..." cuts off what I think is a valuable discussion. I don't feel the scale-up issue should be closed without a thorough evaluation.

I cannot let the discussion in the specification about the size of the Corette plant, base loading, and switch over pass without again taking issue with the concept of parallel operation. The need for parallel operation because the plant is base loaded and any switch over must be minimized is a good argument against the plant selected. Any demonstration of new developing technology is bound to have unscheduled shutdowns and these shutdowns will undoubtably reduce the availability of the bottoming plant. If the availability of Corette is basic to Montana's power system operation, then a less sensitive site should be found for the ATS.

The oxygen enrichment-air heater approaches need to be evaluated in terms of project goals and MHD acceptability. My opinion remains that oxygen enrichment is the best approach for the ATS; not only does it allow more operating flexibility, but eliminates emission clean-up on a fired air heater that is already large and complicated.

As you can see I have some strong opinions on some aspects of the ATS and retrofits in general, but I like to think that some of them result from insights gained from our work at SCE. I am more than ready to discuss any of my comments with MSE at any time. It is vital to the continued

MHD development and commercialization that the ATS be successful, and I will do whatever I can to increase the chances for that success.

Sincerely,

James W. Griswold

Enclosure

cc: Fred Walter - Montana Power Co.
John Leeper

MAIN

CHAS. T. MAIN, INC.
PRUDENTIAL CENTER, BOSTON, MASSACHUSETTS 02199 • TELEPHONE 617-262-3200

January 26, 1983

SUBJECT: Advanced Test System
Corette Retrofit Schematic

Mr. E. W. Ashby
MOUNTAIN STATES ENERGY INC.
Post Office Box 3662
Butte, MONTANA 59702

Dear Mr. Ashby:

I have reviewed the schematic and specification forwarded with your letter of January 17, 1983. Your constraints are well defined, and the design appears to be an absolutely superb responsive to these constraints. The following are some suggestions that you might consider on the order of tweaking a good design concept:

1. Combustor cooling is shown via a cooling system. It might be possible to circulate water from the lower drum in the radiant furnace to the combustor and back to the top drum. The two-phase flow could go directly to the drum, or it might be advantageous to use a flash tank after the combustor, with separate water and steam lines to the top drum. In any event, for a small addition in capital equipment, it might be possible to recover one of the major heat losses from the MHD addition.

2. The heater for the secondary air appears to be in parallel with the economizer section. It might be possible to locate this heater in series with the economizer, which could result in a simpler design. The feedwater for the HRSR is taken from the discharge heater No. 5. It may be possible to take the HRSR boiler feedwater directly after the boiler feedwater pump. The lower temperature of water going into the economizer section could result in an increase in overall retrofit efficiency. The specification did not state an MHD channel or combustor size and, assuming a relatively small MHD channel as compared to the overall plant size, it is quite probable that the suggested change with resulting reduction in extraction steam flow would be acceptable for the turbine.

3. Flue gas for coal drying is extracted ahead of the ESP with a discharge directly to the stack. It is not clear what will become of the seed and ash contained in the flue gas.

The air separation unit will have considerable waste nitrogen at a relatively low temperature, and the compressor discharge will require cooling. You may wish to consider using the waste nitrogen to cool the compressed air with the resulting hot nitrogen used for coal drying or seed reprocessing drying. Also, some recent studies associated with the Advanced Power Train indicate that the drying of coal is much more difficult than had been previously thought, and that it may be necessary to predry the coal before drying in the pulverizers.

4. Flow control valves are shown for both the main steam and reheat lines. You may find it possible to design the recovery boiler so that flow control is not required on the main steam but only required on the reheat. One concern would be the start-up of the heat recovery boiler with the Corette steam generator at full conditions. You will probably find it necessary to have a by-pass from the HRSR main steam line to the cold reheat line, and from the hot reheat line to the condenser with appropriate sprays for temperature and saturation control. This will allow the MHD unit to be started and the HRSR brought up to temperature and pressure so that the steam can be fed into the Corette steam line.

I would like to repeat that the retrofit schematic represents a design that appears to make more sense than anything I have previously seen wherein the intent is to demonstrate the operability of an MHD flow train consisting of combustor channel and HRSR. This approach makes far more sense than an attempt to fund, design or construct a complete MHD power plant. I would like to wish you luck with the project, and will appreciate the opportunity to be kept informed. Also, MAIN will be pleased to review and comment on any aspect of the project wherein you believe we might be helpful.

Very truly yours,

CHAS. T. MAIN, INC.

Jack Noble.

J. H. Noble
Chief Mechanical Engineer
Thermal Power Division

JHN:cas

MAIN

CHAS. T. MAIN, INC.
PRUDENTIAL CENTER, BOSTON, MASSACHUSETTS 02199 • TELEPHONE 617-262 3200

February 7, 1983

SUBJECT: Advanced Test System
Corette Retrofit Schematic

Mr. E. W. Ashby
MOUNTAIN STATES ENERGY INC.
Post Office Box 3662
Butte, MONTANA 59702

Dear Mr. Ashby:

The following is a supplement to my January 26, 1983 letter concerning the subject MHD Advanced Test System.

In your letter of January 17, 1983, you asked several questions regarding the recommended oxygen enrichment, preheat, and size of the topping unit. The following is in response to these questions.

Our studies on a 200, 500 and 1000 MWe station indicate that an oxygen enrichment of approximately 32% by volume (coupled with a preheat of about 1200°F) yields the lowest overall cost of electricity. The 1200°F preheat represents a practical upper limit for preheat which uses the HRSR as the source of energy. We were involved in a rather lengthy review of separately fired preheaters. However, the technology does not exist for a coal fired preheater, and it would be necessary to use either gas or oil. The concept of oil or gas fired preheating is inconsistent with the objective of a 100% coal fired MHD unit. While a combustor enrichment of about 32% is specified, the oxygen percent can be varied slightly up or down to obtain the desired entrance gas temperature to the MHD channel.

NASA has recently completed some studies that indicate that for conventional air separation units (ASU) an enrichment of about 70% (by volume) results in a minimum cost ASU. The 70% oxygen produced from the ASU would then be mixed with normal air to obtain the (32% oxygen) oxidant.

Reference Number 4 of your letter describes an ASU system called the internal compression process. Recent information from the author of this paper indicates that this new process costs about the same as the optimized conventional process. Since there is a significant savings in energy with the internal compression design, we suggest this process be considered in more detail for your ATS.

We concur with the anticipated design parameters (supersonic channel operating at about 4.5 Tesla) for the ATS. Our most recent study indicates that although less efficient than the subsonic channel operating at 6 Tesla, for a small channel, the cost of electricity produced by the supersonic design is essentially the same and, what is far more important, there would be less risk involved.

It would be our opinion that a combustor size of no smaller than 50 MW thermal and no larger than 100 MW thermal would be most suitable for the proposed ATS. This size range would have a number of advantages in that the extrapolation from present combustor work would be relatively modest. If you chose the 100 MW size, then the extrapolation to a combustor for use with (approximately) a 100 MWe turbine retrofit would be reasonable. Also, since the MHD flow train will be a test system, if the size is relatively small compared to the Corette boiler, then the boiler will provide steam stability and perturbations within the MHD system would not result in unacceptable changes in steam flow to the turbine. A 100 MW thermal combustor would support a MHD channel of about 15 MWe and would provide additional steam of about 25 MWe for the Corette turbine. The successful operation of a MHD flow train of this size should demonstrate the viability of the concept and provide sufficient information for scale-up for a full-sized retrofit.

As previously discussed, we are quite interested in receiving a copy of your study on seed reprocessing indicating a potential commercial market for a modest quantity of potassium sulfate.

Again, I would like to wish you luck with the project, and will appreciate the opportunity to be kept informed. Also, MAIN will be pleased to review and comment on any aspect of the project wherein you believe we might be helpful.

Very truly yours,

CHAS. T. MAIN, INC.

Jack Noble.

J. H. Noble
Chief Mechanical Engineer
Thermal Power Division

JHN/ACP:cas

FORM CDIF-279
(REV. 11-80)

SHEET: 1 OF 1

Post Office Box 3767
Butte, Montana 59702

DATE: 1-31-83

TIME:

RECORD OF TELEPHONE CONVERSATION

FROM: G. L. Nelson	PARTY CALLED: Finn Hals
TITLE:	TITLE:
COMPANY: Mountain States Energy	COMPANY: AVCO Everett

TOPICS OF CONVERSATION:

Mr. Hals called to discuss his comments on the DNRC Milestone 2 document which had been sent to him about ten days previously. His remarks are listed below.

1. The enthalpy extraction of 17-20%, which was specified in the report, cannot be achieved. This requirement should be relaxed to 12-14%.

2. The choice of using a supersonic generator with a 4.5T peak magnetic field is a very good one. He was quite emphatic in saying that we should stay away from supersonic channels.

3. The plant schematic which was included as one of the Milestone 2 documents should be modified to show a separate cooling loop for the generator. A separate cooling loop for the combustor may also be necessary. One should attempt to recoup as much of the MHD wall losses as possible through a well-designed cooling system, otherwise plant efficiency will suffer. It may be a good idea to use an external heat exchanger to recover the heat from the generator and combustor.

4. The oxidant preheat temperature should be no higher than 1200°F. This is a critical point. Specifying a preheat temperature higher than 1200°F will greatly complicate the task of building the preheaters, and will run up the costs. Even if you could preheat up to 1800°F, an air separation unit would still be necessary, and if the air heaters didn't work as designed, the whole retrofit project would be in jeopardy.

5. We should look in some detail at the question of motor drives vs. electric drives for the ASU compressor and the blend air compressor. (Johnson and Rudberg are doing this). One point to keep in mind is that the

MHD generator cannot respond to increased load until the compressors are up to speed, and this may agrue in favor of electric drives.

6. It will probably be necessary to do some superheating in the radiant section of the heat recovery system.

7. Do not sacrifice reliability for efficiency.

8. The level of oxygen enrichment should be set at 32-33 mole pct.

Comments on "Specification of Baseline Design"

Corette station choice OK

Define enthalpy extraction - item 1. Better to use ratio of P_{MHD} to P_{th}

make $P_{MHD}/P_{th} \geq 0.20$

Item 2 - Demonstrate that "one or more" of the HR/SR concepts ---- is valid.

demonstrate adequate degree of seed recovery.

Item 4 - Demonstrate achievement of "greater" overall plant efficiency.

In the following paragraph discussion is given of limitation of the hybrid plant. One should note that this is a "Test System" not an MHD/steam power plant.

P. 4, middle paragraph - Another good reason for use of electric compressor drives is that in start-up and operation of the plant is facilitated. This is particularly important in a very new installation.

Lower paragraph - Better avoid concept of heat recovery/seed recovery unit. Better to assign these functions to separate individual components.

P. 5 With 1100-1300°F preheat we do not need 30-34% O_2/wt unless exceptionally high combustor temperatures are needed. If we accept T_3 = 2700K then much less O_2 is needed. The air preheaters suggested (by the writer) are not of nearly such high temperature as those previously considered as alternates to O_2 enrichment - namely 1644K.

Middle paragraph - only partial seed recovery will occur in the convective section. Balance will take place in ESP or bag-house. There may not be a match between time req. for NO_x decomp and time of residence in the radiant section.

Bottom - It is a great mistake not to use the SC magnet. Why don't we advocate the job - that really needs to be done. Even with a

conventional mag. of 4 to 4.5 tesla we should not propose supersonic flow. Better say nothing, or else say subsonic. The plan shows an S.C. magnet.

In general this is a good write-up.

S. Way
2-3-83

Comments Regarding the ATS

Oxygen enrichment and air preheat

Although a system could be used with no O_2 enrichment and 1300K air preheat there would be some problems in development of the preheater. These problems would not be serious, but nevertheless would present an obstacle. A study was made by the writer (reported separately) with O_2 enrichment to the extent of 0.1 mode O_2 per mode of dry air. In this case 2700K flame temperature is realized with 1100°F (867K) air preheat. This would be a better compromise than using the much higher O_2 enrichment suggested in the NASA study. (Parametric Study of Early Commercial MHD/Steam Power Plants). The writer would like to emphasize, however, that eventually we shall be wanting to build MHD plants with less O_2enrichment, or none at all, and that hence attention should be given to making the ATS capable of that mode of operation. I would therefore recommend that (a) the air heater be designed for preheating air to 1300K, (b) the combustor be designed for air/coal combustion and 400 MW_{th}, (c) the generation then be run alternatively at 400 MW_{th} without O_2 enrichment or at 500 MW_{th} with O_2 enrichment. The same generator channel would suffice for both. One could also operate at intermediate points, e.g., 450 MW_{th} and 5% O_2 addition.

Criteria for size of the ATS

These criteria include (a) realistic assessment of problems, (b) avoidance of too large a scale up from the CDIF, (c) avoidance of too large a scale-up from ATS to a first commercial plant. The ATS should therefore fall between the commercial plant and the CDIF, with greater emphasis on matching the commercial plant. A good commercial plant can be conceived at 500 MW_{th}. The CDIF is 50 MW_{th}. Therefore the level proposed of 250 MW_{th} for the ATS

seems a good one. This is a 2.24 L scale-up from the CDIF, and it would enable us to pin-point most problems of the MHD/steam plant.

Plant controllability

Controlled quantities are air flow, O_2 flow, fuel flow, B-field, seed level and electrical load. A special study must be made of start-up, shut-down, load change and emergency conditions. In general it may be said that start-up would be by orderly, coordinated increase of flows and electrical loading, with (probably) design B-field and seed fraction. In this way a design operating condition is gradually approached and realized. Sensors must be provided for not only quantities to be controlled but also quantities to be observed, in evaluation of performance and analysis of test data. Controllers, linked to the sensors, and having the function of matching operating parameters to setpoints must be provided. During start-up, load-change, etc., the setpoints for the various flows, etc. must be advanced. Rather than do this manually (by agreement and coordination in the control room) it should best be done automatically according to a predetermined program, and means of sequential control to advance, or change the setpoints. Human intervention than would occur only to modify or change this program.

In general, there are two types of instrumentation; control system instrumentation, and data collection instrumentation. Test monitoring instrumentation is a part of the latter.

Much greater emphasis should be placed on data acquisition than is the case in the present CDIF.

A well designed MHD system should have no problems of "hunting", instabilities, fluctuating temperature excursions and similar phenomena. Avoidance of these occurrences require careful system design. Design reviews should focus on these possible trouble sources.

ELECTRIC POWER RESEARCH INSTITUTE

EPRI

February 21, 1983

Mr. E. W. Ashby
Mountain States Energy, Inc.
P.O. Box 3662
Butte, Montana 59702

Dear Mr. Ashby:

Your letter of January 17th with the attached schematic and specification has been review and comments are as follows:

The specification addresses trade-off between oxygen enrichment and the amoynt of air preheat optimum for a retrofit cycle such as you propose. Probably we should not plan through this first generation of MHD plants any more advanced components than are absolutely necessary. In terms of your question, we should build an oxygen-enrichment plant to satisfy the required heat balance of the cycle, and not do any more air preheating than one can purchase "off the shelf" heat exchangers to perform.

Historically, when the utility industry has faced the dilemma of how large to build a first-generation advanced technology, the question is answered by the manufacturers involved in the components the plant will require. One of the components or products in the MHD plant which are not now available for purchase will probably limit the size of such a plant. I suggest you contact possibly manufacturers of the various new products required in the plant and find out how large a component they could build based on presently developed technology.

You indicate there is a question of plant controlability and indeed, there probably is. My suggestion is that you only show a master controller for the channel and seed regeneration funcrion, with an overall plant data and evaluation computer. The exact functions of the controller can only be determined when the major equipment in the plant is designed and tests have been run at the various laboratories to establish the most promising modes of control. Historically, control systems are the last thing in the powerplant to be designed.

The thoughts represented here are superficial suggestions based on our general experience in other advanced technology types of plants. They do not represent any depth of engineering work that has been performed on an MHD retrofit plant design.

Very truly yours,

A. C. Dolbec
Manager
Power Generation

ACD:tco

cc: L. Angello, EPRI
F. Walter, Montana Power Company

February 10, 1983

To: Gordon Nelson, Mountain States Energy

From: Roy M. Johnson, Ph.D, and
Donald A. Rudberg, Ph.D., P.E., Consultants

Subject: Notes on the MHD Retrofit Review of the Correte Steam/Electric Power Plant

General Remarks About the Retrofit Review and the Plant

Because no dynamic simulation of a combined plant with either a supersonic channel or the proposed steam generation system has been done, subsequent comments are based on extrapolation of experience with simulated operation and control of plants having subsonic channels, in which a single HRSR provides all steam. Although well-considered engineering estimates have been made, complete heat and mass balances have not been calculated, so that some variation from quoted values of heat and mass can be expected.

According to MPC documents, full-load firing of the Corette plant is 22.04 Kg/sec (174,897 lb/hr) of Montana Rosebud coal, with 23.5 percent moisture, and thermal content of 20.884 MJ/Kg (8980 BTU/lb), for a total of 460.2 MWt coal input. At rated steam conditions of 12.41MPa/867K/867K (1800psi/1000F/1000F), the expected performance is 163.0 MWe at a heat rate of 8051 BTU/kw-hr for the turbine-generator unit. According to experienced operators, if sufficient boiler and airflow capacity were available, the turbine-generator will provide electrical output of 173 MWe (192,000 KVA at .90 power factor).

During MHD firing with the initial configuration, the heat rate will change little because the turbine-generator will be operating at full-load. A thermal input to the existing furnace of slightly over half of full-load values (to accomodate off-design heat transfer) is expected when the MHD unit is supplying one-half of the steam required for full turbine-generator output. Operation of the existing boiler at turn-down to 50 percent of the expected performance of 163 MWe output is quite feasible, since the plant was observed operating at 70MWe output (43 percent of rated output) very stably.

The sequel is a set of remarks directed to various aspects of the retrofit, not in any particular order. They are subject to modification as more information becomes available, but they do represent our best engineering judgement under the circumstances.

Operation of the Initial Retrofit Concept

Under conditions that 50 percent of the total thermal input required for steam generation must come from the exhaust of the MHD test unit, and that both the blend-oxidant compressor (BOC) and air separation unit (ASU) compressor are driven electrically, we expect that approximately 303 MW total thermal input will be necessary for firing of the topping plant. Of this, about 33 MWt will come from compressing and preheating of the oxidant to 867K (1100F) in a recuperative heater, leaving 270 MWt to be delivered by coal input, which is estimated to be 10.8 Kg/sec (85,715 lb/hr) of typical Montana Rosebud coal, dried to 5 percent moisture. We have used a high heating value of 24.965 MJ/Kg (10,735 BTU/lb) for such pre-dried coal.

With expected enthalpy extraction of 42 MWe (14 percent of the thermal input to the combustor), gross electrical output will be 205 MWe, assuming that additional turbine-generator capacity reported by plant operators (the 180 MWe level) is not used. When the electrical power requirement of about 20 MWe for oxidant compression and the oxygen plant is subtracted, net power output will be about 185 MWe (less normal load of pumps, compressors, lights, etc.). Cooling losses of 17 MWt from the combustor-nozzle (5.5 percent of combustor input) and 15 MWt from the channel (5.0 percent of channel input) are expected, so that about 229 MWt will be exhausted into the diffuser and HRSR. This is half of the approximate 458 MWt of coal firing of the existing Corette boiler under full load conditions. These observations do not yet consider use of the 32 MWt combustor-nozzle-channel (CNC) cooling output for any specific purpose.

Oxidant Conditioning

In order to attain the core gas temperature for adequate MHD power extraction, suitable oxidant preheat vs. oxygen enrichment guidelines for subsonic generators have been found to range from 867K (1100F) @ 34 percent mole fraction oxygen to 1033K (1400F) @ 30 percent mole fraction oxygen (extrapolation to supersonic generators has not been made). Simulations have been run with 867K preheat @ 30 percent mole fraction and it was found that although operation was satisfactory, it was just above the knee of a declining power extraction curve. Reduction of either preheat temperature or oxygen enrichment resulted in fairly rapid drops in power output from the channel. Considering the likelihood of off-design operation of heaters and oxygen blending equipment, we do not recommend operating so close to the boundary of an acceptable regime. A boost in preheat temperature and/or oxygen mole fraction to the range indicated is recommended. The efficiency penalty paid for such conservative operation is small.

Combustor-Nozzle-Channel Cooling and Feedwater Heating

Initial thoughts on use of CNC cooling output are directed toward the feedwater heaters. If the plant is operated with the last feedwater heater removed from service (heater five, operating on steam extracted from the high-pressure turbine outlet), and replaced with CNC cooling water, a higher steam mass flow through the IP-LP turbine is possible, yielding

increased shaft output to the main generator. A slightly higher heat rate can be expected, up to about 8160 BTU/kw-hr from 8051 BTU/kw-hr. However, this cannot really be considered a loss since CNC cooling water was not of sufficiently high temperature to be useful much of anywhere else, and might have been rejected.

Indeed, there still might be a problem in using it to provide feedwater heating as a substitute for heater five. Input feedwater temperature from heater four will be 474.4K (394.0F, 371.0h) and outlet temperature will be 512.6K (462.7F, 445.2h), meaning that to construct a reasonably sized heater, CNC coolant must be at about 544K (520F) entry temperature to the substitute heater. In order to keep water from boiling at that temperature (and allowing a reasonable operating margin), a pressure of around 8.27MPa (1200 psi) is required. This may be possible in combustor-nozzle cooling, but it is is not feasible in channel cooling hoses, so some other means of transferring heat to the new heater will be necessary, e.g., a high-boiling-point intermediate coolant. The actual thermal transfer in the new heater is 25.5 MWt, based on a feedwater flow of 147.6 Kg/sec (1171480 lb/hr), which leaves about 6.5 MWt of the cooling output of the CNC unused.

As an alternative in the event that the required 561K temperature of CNC coolant is too high, feedwater heater three is another candidate for replacement. It has thermal transfer of about 27.6 MWt under high operating conditions, leaving 4.4 MWt of CNC cooling unused, and has inlet and outlet temperatures of 387.6K and 441.9K (237.6F, 205.8h and 335.4F,306.2h), respectively. This calls for pressure in the 2.93MPa range (425 psi, which includes operating margin) to prohibit water boiling. Some modification of the feedwater flows will be necessary since heater three acts as an open heater insofar as inflow and outflow are concerned, i.e., drain flow from higher temperature heaters is combined with the feedwater flow between of heater number three and heater number four. If steam turbine drives are used for the BOC and ASU, this is the preferred heater substitution because of comparative effects on turbine steam flows. If steam drives are not used, it has no special recommendation in that regard.

For either of these suggestions, a new heat balance of the steam cycle should be made, with consideration given to the changes of waterwall steam generation, superheat and reheat requirements. The first suggestion should yield greater output from the turbine-generator, but the choice depends upon feasibility of cooling at higher temperature and pressure. For either modification, some small increase in heat rate is expected.

Steam Drives for Air Separation Units and Oxidant Compression

Use of electric drives on the air separation unit (ASU) compressor and the blend oxidant compressor (BOC) drives eliminates some of the interaction between the Corette steam generator and the HRSR. If the plant is to be used for primarily demonstration purposes, this will be advantageous through the coupling reduction. Fixed-speed motor drives will require use of inlet guide vane control of mass flow, resulting in some reduction of efficiency. This is probably no critical issue. Overall

plant output to the grid will also be reduced from gross output as noted above.

If the decision is made to have a more test oriented facility (and we think it would be reasonable in this case), the BCC and ASU compressor can be turbine driven by steam from the HRSR and main steam generator, thereby allowing evaluation of dynamics of a more complete plant. In addition to providing higher linkage of the steam systems and corresponding testability, the steam turbine drives will (1) provide greater net plant output and (2) will allow the combined plant to be operated at lower turn-down from maximum, providing that the topping plant can be turned-down with stability.

First, assuming that scaling uncertainties will limit the MHD topping plant to 303 MWt input, net combined-plant output will approach 205 MWe as a result of generating steam on-site for the BCC and ASU drives. When steam drives are used for the compressors, not all the steam generated by the 228 MWt exhausted to the HRSR will be available to power the main turbine-generator. About 18.2 MW steam power will be required by the combined BCC and ASU turbines, a value that depends somewhat on oxygen mole fraction. Thus, to drive the turbine-generator at full load, the existing boiler will have to be fired at a higher level to make up that 18.2 MW of steam not available from the HRSR. Rather than firing at a 50 percent level, the Corette steam system will raise to a coal input near 278 MWt or 61 percent. Coal consumption must increase accordingly, so no improvement in efficiency is forseen.

Second, the Corette furnace has been observed firing stably at 43 percent of full rating, so if the channel can be controlled to about 70 percent of rated load, it should be possible to reduce combined plant output to about 70 percent of full output, or 144 MWe before minimum firing level of the furnace is reached. These figures are derived from the min/max furnace firing range of 43/61 = 70 percent. So the range is from 144 MWe to 205 MWe. This compares to a min/max range of 43/50 = 86 percent when the BCC and ASU are electrically driven, which gives a more restricted range from 159 MWe to 185 MWe.

As counterclaims against such advantages of steam drive for the BCC and ASU drives, certain non-optimal changes are likely. First, increased feedwater flow is necessary to accomodate compressor drive steam. An increase from 147.2 Kg/sec (1,168,561 lb/hr) to about 163.4 Kg/sec (1,297,000 lb/sec) of feedwater is likely to be required for an ideally balanced system of steam generation and consumption. This pushes hard on the capacity of the existing pumps so that a small auxiliary pump may be required, plus additional condensing capacity. On the positive side, increased feedwater heating will be required so that the 5-6 MWt excess of CNC cooling may be absorbed effectively.

A more difficult problem is balancing the new steam demand with steam generation. The best control of turbine power is attained with a fixed pressure supply which is flow regulated with governor valves, i.e., nozzle flow directed through impulse stages, followed by reaction stages. Thus source of BCC and ASU drive steam is ideally from the main steam supply.

But this presents problems in what to do with the exhaust steam from the two turbines. If they are exhausted to the cold reheat header, both pressure and flow in the hot reheat header are increased. Expected full-load HP turbine flow is 138.3 Kg/sec (1,097,455 lb/hr) and IP inlet flow is 119.7 Kg/sec (950,106 lb/hr). To give necessary shaft power, steam flow through the BAC and ASU units must be about 54.3 Kg/sec (431,000 lb/hr) when fed from high pressure steam and pressure in the reheat system remains at design values. This flow will combine with the IP inlet flow to give 174.0 Kg/sec through the IP/LP turbine combination, an unworkable value which completely upsets the balance of steam generation and consumption. Furthermore, reheat system pressure will not remain at design value, but will rise appreciably, making flow control more difficult.

An second approach is to operate the ASU turbine from main steam and the BOC turbine from reheat steam. The ratio of power extraction between the existing HP turbine and the IP/LP combination is very nearly 1:2.5, and it would be desireable to have any additional steam drives approximate that same ratio. The objective is to keep reheat system pressures near design values as load changes, thereby minimizing flow deviations. The ratio of power for ASU and BOC drives is about 1:1.9 when 30 percent mole fraction oxygen is used. This will decline to around 1:1.7 as 35 percent mole fraction oxygen is approached. These ratios are certainly of reasonable value and they make a more complete evaluation of the configuration in order.

Some interesting (but we hope not insurmountable) control problems are forseen with such an arrangement. As mentioned, control of turbine power (or flow) is much more easily attained if supply steam is well-regulated in pressure. Thus the ASU drive would be highly controllable. The same cannot be said of the BOC drive. It would receive steam from the hot reheat header, which is not pressure regulated. Control with a governor valve system is much more difficult, and may require a special design. Generally, turbines driven from unregulated reheat steam are reaction turbines that have no flow control mechanism at all, being dependent only on supply pressure. One approach to control of oxidant flow is to use inlet guide vanes on the compressor; another is to direct bypass steam to the BOC turbine during rapid load increases.

Another problem associated with operation of the BOC turbine from reheat steam is that of supplying adequate steam during rapid load increases. There is a tendency to starve the BOC turbine during such times so that MHD firing is restricted. This is a problem that has long been observed in simulation of combined-cycle plants in which all firing is through the MHD combustor. However, the major portion of firing in the Corette retrofit is through the existing furnace and BOC turbine steam starvation may not be a critical problem. Simulations will provide reasonable guidance.

As a third possibility, the positions of the ASU and BOC drive turbines can be interchanged, so the the BOC is driven from main steam and the ASU is driven from reheat steam. The ratio of power requirements then becomes much less favorable, ranging from 1:.53 to 1:.59 as oxygen mole fraction ranges from 30 percent to 35 percent. Despite such a power ratio

disadvantage (the ideal ratio is 1:2.5), control advantages make dynamic evaluation of the configuration very worthwhile. There is no tendency toward steam starvation of the BOC turbine and it becomes highly controllable through governor valving. Furthermore, a natural balance between steam generation and consumption occurs, so that main steam temperature and pressure are very little affected by load changes. Because the ASU turbine is driven from reheat steam, its dynamics cannot be made very fast and control through steam flow modulation is not attractive, for the same reasons quoted above when the BOC turbine is supplied by reheat steam. Thus some form of slow inlet guide vane control is more likely. But the ASU turbine does not need fast control. In fact, its response can be made contrary to load change demand for moderate time periods if that will improve overall plant behavior. This is because a 2-3 hour supply of oxygen will be stored for startup and other topping cycle needs. Sluggish ASU response is of no consequence, and because of its non-critical nature, the ASU provides an added degree of freedom in control. The major problem seen with such an arrangement is the unfavorable ratio of BOC turbine power to ASU turbine power, and associated potential disturbance of steam flow through the main turbine IP/LP section.

Damage and outage recovery control problems may be less severe with steam turbine drives for the ASU and BOC. Should the MHD plant lose firing, only 39 percent of steam required for full-load operation of the turbine-generator would be lost. Indeed, some of the steam generated by residual heat in the HRSR can still be supplied while the main boiler is being fired upward. This would have to be carefully monitored to avoid wet steam carryover. Not all steam could be diverted since some cooling air/oxidant must be pumped through the ITCH to prevent tube burnout.

Should the MHD channel lose load, the situation for the topping plant and HRSR is again less severe when steam drives are used for the BOC and ASU. Excess steam can be vented while decisions are made about shutdown of the MHD firing system, but the steam venting will be less since some drive will still be required for cooling air/oxidant flow.

General Control Aspects

Outside of the ASU and BOC turbine control problems mentioned, the remainder of the combined-cycle system appears to have generally good control potential. Use of the exisisting feedwater pumping system (condensate and high-pressure pumps), plus a small auxiliary if required, should be well-matched to expected flow and pressure requirements.

A possible problem exists in drum level control of the combined steam generating units under load perturbations. Level changes may become significant under loss of load by either the main generator or the MHD generator, or under complete loss of the MHD unit, including gas flow to the HRSR. It is expected that the HRSR will have an individual drum associated with its steam generating unit. But the steam generating systems are only semi-independent, being linked by water and steam flows. The combined units should be dynamically modeled to determine the nature of interactions.

Because it may be desired to operate the Corette plant and the MHD topping unit in semi-independent manners, say for tests of the MHD unit, while holding overall power output at levels required by the Montana Power system, additional control modes may be necessary. No significant problems are currently anticipated with coordinating output of the combined units to meet grid requirements. Basically, when the MHD topping plant is fired independently, firing of the existing boiler can be adjusted to compensate for changes in MHD output. Steam flows that drive the SCC and ASU are fundamentally linked to the MHD operating level, so that oxidant pumping needs, HRSR thermal input, and resultant steam generation will all move together. The HRSR will also provide some steam to the main turbine at all MHD firing levels.

Subsonic vs. Supersonic and Electrical Configuration Considerations

The question of whether the retrofit MHD topping cycle should be configured either subsonic or supersonic is not clear cut and depends upon the electrical generator configuration as well. We begin by listing some of the advantages and disadvantages of each configuration:

Subsonic system

1. The system is very stable in Faraday connection to large global transients about the full load design point.

2. The current density/electrode is lower for a fixed amount of design power output because of the increased wall surface area.

3. The thermal heat losses through the generator walls are larger because of the increased surface/volume ratio for a given design power output, (pressure heat transfer effects are however more favorable.)

4. For a given amount of power output, the magnetic field flux density must be in the 6 Tesla range for optimum performance.

5. Operation at reduced power output is quite stable, especially for Faraday connection.

Supersonic System

1. Supersonic operation at the same power output level is possible using a smaller value of magnetic field strength.

2. The generator, being smaller than the equivalent subsonic generator in surface area size for the same mass flow and power output, has smaller thermal losses, (to first order.)

3. The current balance/electrode is satisfactory only at design load for diagonal connection.

4. The stability of operation of supersonic flow channels is poor at reduced load operation, particularly for two-terminal diagonal connection.

5. The current density and heat flux/electrode are higher for supersonic operation. All other things being equal, this would indicate a higher incidence of arc concentrations.

Before elaborating on these statements, we will present several possible modes of operation of a Corette MHD retrofit plant.

Possible Modes of Operation of a Corette MHD Retrofit Plant

Three possible modes of operation would appear to be useful for consideration:

1. The total power output of the Corette MHD retrofit combination would approximate that which Corette can deliver now, (163 MWe.) The MHD topping cycle, when operating, would be operated at design power output.

2. The total power output of the plant combination would equal the full load capacity of the combined plant. This would be approximately 215 MWe, taking into consideration the present excess turbine-generator capacity of 10 MWe.

3. Depending wpon load requirements, the retrofit plant output would be varied with variable topping and bottoming cycle loading.

Mode 1 would provide the simplest control and operational environment for the MHD topping cycle since its output would essentially be always constant when in operation. Based upon an assumed topping cycle size of 40-50 MWe, the Corette boiler can be operated stably at about the required reduced level. At less than 84 percent of this level the Corette boiler may become difficult to control on a steady state basis. When the MHD generator must be tripped from the line, the overall plant output could be quickly restored by increasing the power angle of the Corette turbine generator. The load change rate of 5%/minute presently in use at the plant would allow 180 MWe Corette load to be reassumed in approximately 6 to 7 minutes. MPC system reserve is well able to handle the short increased demand during most periods of the year.

Mode 2 would provide a high uptime demand requirement on the MHD topping cycle and the additional requirement for considerable steam venting upon MHD trip. The topping and bottoming cycle control for this mode would be more complex unless the MHD generator can be stably operated at reduced loading. This mode would closely approximate the usual base-load plant conditions and in our opinion is too optimistic an operational assumption for the present state of MHD technology. The mode could be tried however on a slack system, short-time basis for gathering operational control data.

Mode 3 would provide the greatest flexibility of operation and would provide the most desireable conditions for obtaining additional engineering data. Depending upon system load requirements, MPC might desire to experiment with MHD peaking usage if the flexibility and reliability of the channel could be assured. As observed earlier, control of this mode would also be complex, but not unreasonable.

Discussion

We will now elaborate on the question of subsonic and supersonic operation in the context of the above operational modes before giving our preliminary conclusions; it must be understood that definitive conclusions concerning these questions cannot be given without additional studies and simulations.

First some perspective comments. We believe that the initial goal of the proposed retrofit would be to provide reliable bottoming cycle power generation on essentially a continuous basis while providing a facility where a MHD topping cycle can be studied further in a commercial environment. The efficiency of the combined plant will be of secondary importance provided the overall efficiency is not less than that possible in the stand-alone bottoming cycle configuration. Since the scale-up of the MHD generator required is quite large in comparison to any existing coal-fired MHD test facility, the technology should build conservatively upon our known data base. The cost of the proposed retrofit should be as low as possible consistent with obtaining as many of the above goals as possible.

The supersonic channel possesses the distinct advantage that the magnet requirements can be reduced with respect to magnet volume and peak required magnetic field. At any load factor for the Faraday connection and about the design load factor for the diagonal generator, the power output per unit volume varies proportional to the square of the velocity-B field product. Thus if the velocity in the supersonic case is increased by 100% over its value in the subsonic case, the magnetic field B may be reduced to half of its value for the same power output. However, if the ideal induction is taken to be 6 Tesla, the magnetic field will have to be reduced to approximately 2.5 Tesla to significantly reduce the cost and power requirements of the magnet, since this is the upper saturation limit of all but very exotic magnet materials. Thus the channel will have to be operated at above Mach 2, to achieve the same power output. This is quite high compared to existing experience and would require a sharply negative velocity gradient within the channel to mesh efficiently with a reasonable diffuser design. Although there are no apparent reasons such a design would not work reasonably at design power, the stability at reduced loading would appear to be a serious question. The control of a Faraday generator would have to be quite tight and flexible concerning individual electrode current loading to make this workable; a two-terminal diagonal configuration would perhaps not be workable at all off design. Thus, although supersonic operation would greatly simplify the magnet cost and operational problems, it is not without significant problems, particularly if part load operation is desireable.

Apart from magnet considerations, the remaining questions of operational characteristics of super vs. subsonic operation also must involve the question of whether the generator is diagonally or Faraday connected. The nominal, first order connection operational characteristics are compared in Figure 4.6, page 66 of Rosa's book. These characteristics hold for either subsonic or supersonic operation. The diagonal generator provides greater output voltage for a given output current which is a slight cost advantage with respect to inverter or step up voltage transformer winding requirements. The slope of the of the voltage-current characteristic is however, quite steep leading to greatly decreased power output and stability of operation at other than a very small range of values about the design load factor. Further, because of electrode current imbalances, the performance at of-design load is particularly inefficient. This is only correctable if the connection is augmented by the use of electrode current balancing shuffle circuits. This then raises the cost of the power consolidation circuitry to a level comparible with that of Rosa consolidation necessary for a Faraday channel. The Faraday channel, with Rosa consolidation, provides complete control of the power output of the generator in a manner which may be optimized with respect to the particular load condition desired. The Faraday connection is also quite broad with respect to variable load factor while still operating at high efficiency. Further, detailed transient studies indicate that the global imposition of substancial faults on the Faraday generator are well tolerated in the subsonic case. Some additional work is now being carried out which may partially compare these results with what may be expected on diagonal and supersonic channel designs. However, much additional work needs to be done to gain answers to this question. Nevertheless, it is assumed, because of the large amount of generator experience gained previously at AVCO and the CDIF, that the diagonal channel connection is probably the most conservative.

If the Faraday connection with complete consolidation and individual electrode current control is desired, forced commutation or pulse width modulation is required.

The question of forced or line commutated inverter system is strongly affected by the time frame in which the retrofit is to be made. If the retrofit were to be made immediately, the choice would probably be to use a line commutated system based upon the Westinghouse design because of the present state of the available semiconductors. However, with the silicon-controled-rectifier, (SCR) and (especially), power transistors advancements made recently, there is a strong shift in advantages toward forced, or load adaptive designs. For example, the new pulse-width-modulation designs using power transistors make possible the capability of dynamic current control and interruption in either Faraday or multi-tap diagonal configurations. This would permit extinction and control of arc currents without disturbance to the rest of the generator. The cost and complexity of these systems should be greatly reduced compared to Rosa consolidation designs.

Conclusions

The preliminary conclusions may be summarized as follows:

1. If mode 1 operation is desired, it appears possible to operate supersonically with reduced magnet requirements and a two-terminal diagonal connection. The design of the generator would be a complex compromise necessary to achieve the objectives of nearly equal electrode currents with a steeply negative velocity gradient to meet reasonable diffuser design requirements. An inverter system based upon the CDIF Westinghouse design could then be used. This design would be very inflexible in operation, would be the most conservative design, and would provide very little advancement of MHD technology other than providing commercial operating experience and long duration test data. A considerable amount of power factor correction VARS would have to be supplied for this system.The control system design to permit stable operation of the system would appear to be severe.

2. Mode 3 operation would be most flexibly carried out using Faraday operation, (or at least multi-tap diagonal connection with shuffle circuits) and subsonic generator operation. This would involve a superconducting magnet requirement and would be more expensive than the mode 1 design. This mode of operation, if it can be afforded, would advance the state of MHD significantly over its present state with respect to generators, power conversion technology, and control.

3. Mode 3 supersonic operation would require strong load control on the MHD generator and probably require flexible, complete consolidation of a Faraday generator. If a high field, superconducting magnet were used the control of the generator becomes less severe and restricted. If the diagonal connection were used it would have to be at least multi-tap diagonal in configuration, perhaps with some shuffle circuits required.

February 10, 1983

To: Gordon Nelson, Mountain States Energy
From: Roy M. Johnson, Ph.D, and
Donald A. Rudberg, Ph.D., P.E., Consultants
Subject: Notes on the MHD Retrofit Review of the Correte Steam/Electric Power Plant

General Remarks About the Retrofit Review and the Plant

Because no dynamic simulation of a combined plant with either a supersonic channel or the proposed steam generation system has been done, subsequent comments are based on extrapolation of experience with simulated operation and control of plants having subsonic channels, in which a single HRSR provides all steam. Although well-considered engineering estimates have been made, complete heat and mass balances have not been calculated, so that some variation from quoted values of heat and mass can be expected.

According to MPC documents, full-load firing of the Corette plant is 22.04 Kg/sec (174,897 lb/hr) of Montana Rosebud coal, with 23.5 percent moisture, and thermal content of 20.884 MJ/Kg (8980 BTU/lb), for a total of 460.2 MWt coal input. At rated steam conditions of 12.41MPa/867K/867K (1800psi/1000F/1000F), the expected performance is 163.0 MWe at a heat rate of 8051 BTU/kw-hr for the turbine-generator unit. According to experienced operators, if sufficient boiler and airflow capacity were available, the turbine-generator will provide electrical output of 173 MWe (192,000 KVA at .90 power factor).

During MHD firing with the initial configuration, the heat rate will change little because the turbine-generator will be operating at full-load. A thermal input to the existing furnace of slightly over half of full-load values (to accomodate off-design heat transfer) is expected when the MHD unit is supplying one-half of the steam required for full turbine-generator output. Operation of the existing boiler at turn-down to 50 percent of the expected performance of 163 MWe output is quite feasible, since the plant was observed operating at 70MWe output (43 percent of rated output) very stably.

The sequel is a set of remarks directed to various aspects of the retrofit, not in any particular order. They are subject to modification as more information becomes available, but they do represent our best engineering judgement under the circumstances.

ATTACHMENT #6

In order to address all the comments received from reviewers of Milestone #2, the comments have been categorized into succinct summaries with responses made to these categories. However, in some cases it was felt that specific responses were warranted.

SUCCINCT SUMMARIES

Reviewer Comment: Parallel MHD Retrofit -

Bottoming Cycle Operation: Potential adverse effect on availability of the Bottom Cycle.

Response: These comments express clearly valid concerns. However, the operational problems inherent in repeated cycling of the retrofit cycle have been discussed in detail with the host utility and appear to present no adverse impact on the projected operational mode of the selected Bottoming Plant.

Reviewer Comment: Parallel MHD Retrofit -

Bottoming Cycle Operation: Difficulty of mixing steam from two systems.

Response: It is agreed that an "ideal" ATS or, for that matter, an ideal commercial retrofit would not incorporate steam mixing. In any MHD retrofit design, a choice must be made between either mixing the two steam flows or using the existing boiler as the heat recovery unit. The latter choice will involve modification to the existing boiler and will also introduce unknown

wear and corrosion factors into the boiler, due to the fact that the flue gas from the MHD power train will be laden with seed products. It is very unlikely that the host utility would permit such a gas-stream tie-in, particularly for the first retrofit. This is the reason for specifying a steam tie-in.

It is also recognized that a relatively sophisticated control will be required to mate the MHD retrofit to the selected bottoming plant. The selected mode of operation is obviously a trade-off involving considerations of anticipated limited funding (affecting the scale of ATS) and availability of appropriate host bottoming plants.

Regarding the technical rationale for mixing steam, it does not appear that development of suitable controls will present the overwhelming difficulties some reviewers suggest. In any event the development of these controls is not superfluous since early "commercial" MHD retrofits will probably incorporate steam mixing.

Hence, the selected mode of operation is consistent with both demonstrating that MHD "works" to prospective user utilities as well as to making a

contribution to the development of MHD as a viable generation technology - both goals of the ATS program.

Reviewer Comment: Net thermal efficiency of combined retrofit/bottom cycle: Necessity or desirability of specified MHD component efficiencies and overall plant efficiencies.

Response: For the ATS to be a credible "Test System", in addition to demonstrating that MHD "works", appropriate design requirements (efficiency, etc) must be specified for the MHD equipment consistent with the requirements for providing a technical base from which to confidently scale the ATS results to commercial scale.

The requirements so placed on the MHD components from a technology point of view lead to a system that will not degrade the performance of the original plant and may potentially provide a modest increase.

It is emphasized again that these requirements are primarily technology based and are necessitated by the requirements that the ATS make worthwhile technical contribution to eventual commercialization as well as demonstrate that MHD "works". Both are essential requirements.

Reviewer Comment: Combustor Cooling: Efficient use of recovered heat.

Response: We agree with the comment and intent to recover as much heat as practical from MHD components within the constraints of not adding complexity and, consequently, increasing the technical risk of this design.

Reviewer Comment: Boiler feedwater heating: Extracting HRSR Boiler feedwater immediately following the Boiler Feedwater Pump.

Response: The suggested modification will result in a somewhat improved thermal efficiency of the plant. This change would require modifications and controls to the existing Corette Feedwater Heater Flow Configuration when the MHD Retrofit is operating. This design option is the subject of continuing study. However, the operational complexity and additional modifications to the existing plant may not justify a small incremental improvement in heat rate.

Reviewer Comment: Coal and Seed Drying: Suitability of Flue Gas for drying.

Response: Resolution of these comments will be made when establishing the functional and operational requirements in Milestone 4.

Reviewer Comment: Simplified steam control: Possibility of elminating main steam control.

Response: The suggested simplification to the control of steam flow from the MHD and existing boiler is appropriate and has been incorporated into the design.

SPECIFIC COMMENTS

Reviewer Comment: The ATS should be designed for very low or no oxygen enrichment with 1300°K (1880°F) air preheat.

Response: The ATS design should follow the guidelines set by the Phase I Study[2], which represents the utility viewpoint. That document calls for the ATS to be a coal-fired open cycle MHD topping unit with oxygen enrichment. Large, high temperature recuperative type air heaters will require significant development work before they can be used reliably, and thus are not appropriate for a project such as this which should rely on existing MHD components and test experience insofar as possible. We do agree with this reviewer in his belief that ultimately, oxygen enrichment must

be superseded by high temperature air heaters if MHD is to fully realize its potential efficiency gains.

Reviewer Comment: Electric drives for the blend air compressor and the air separation unit compressor are preferable to steam turbine drives because they provide for easier plant start-up and also do not change the steam loading of the main turbine.

Response: This problem is the subject of an on-going study. The efficiency of the plant could be increased slightly by going to steam drives, but this would be at the expense of a more complicated design, and would require modification of high pressure steam lines. It might also adversely impact the controllability of the main turbine in some transient situations. The original specification of motor drives will remain in place unless the above questions can be resolved.

Reviewer Comment: The design objectives specified in the Milestone 2 report do not agree with those developed in the DNRC Phase I Study.

Response: We do not believe there is any conflict between the design philosophy adopted by MSE and that which is represented in the Phase I Study. In regard to the reviewer's statement that MSE has added an unwarranted

efficiency requirement, we would respond by saying that if the ATS is built and demonstrates an overall lower efficiency than that of the original Corette plant, it would be difficult to interpret that as a convincing demonstration of MHD technology. Indeed, the MPC report which is referenced by the reviewer(2) states, "Test results from the operation of the Advanced Test System must reveal that theoretically predicted heat rate efficiencies will be attainable with a commercial size facility". This would appear to be substantially equivalent to the requirement that plant efficiency should not be degraded by retrofit. The other performance requirement of a minimum enthalpy extraction of 19-20% has been relaxed considerably to a minimum of 10% as noted in Section 2.1. Enthalpy extractions below 10% would almost certainly result in a reduced plant efficiency. This requirement has been retained in its modified form in order to insure that some kind of minimal performance requirement is established for the major MHD components. Simply requiring that overall plant efficiency should not be reduced does not impose any restrictions on the manufacturers of MHD generators. Similar arguments hold for the MHD combustor and the heat recovery system.

Reviewer Comment: The selection of a supersonic channel may not be wise because when operating at off-design conditions it may be difficult to control and may exhibit poor steady-state performance.

Response: The supersonic generator was chosen for three reasons: reduced magnet costs, greater experience with supersonic channels, and analysis results. The question of off-design performance of subsonic vs. supersonic channels can only be definitively answered when more test experience has been gained from running large subsonic generators.

ATTACHMENT #7

Mountain States Energy Inc.
POST OFFICE BOX 3662
BUTTE, MONTANA 59702

INVOICE

Date: February 18, 1983
Contract: DNRC Milestone III
Invoice No.: DNRC-03

Department of Natural Resources
32 South Ewing
Helena, MT 59620

Direct Labor	$15,274.45	
Fringe	6,375.54	
		$21,649.99
Overhead		8,631.14
Other Direct:		
Travel	$ 751.90	
Computer Support	1,995.42	
Contract Services	4,470.00	
Supplies	14.70	
		$ 7,232.02
General & Administrative		7,636.55
TOTAL COSTS		$45,149.70
Fee		$ 5,062.50
TOTAL INVOICE		$50,212.20

ATTACHMENT #8

ESTIMATED COSTS
MILESTONE NO. 4

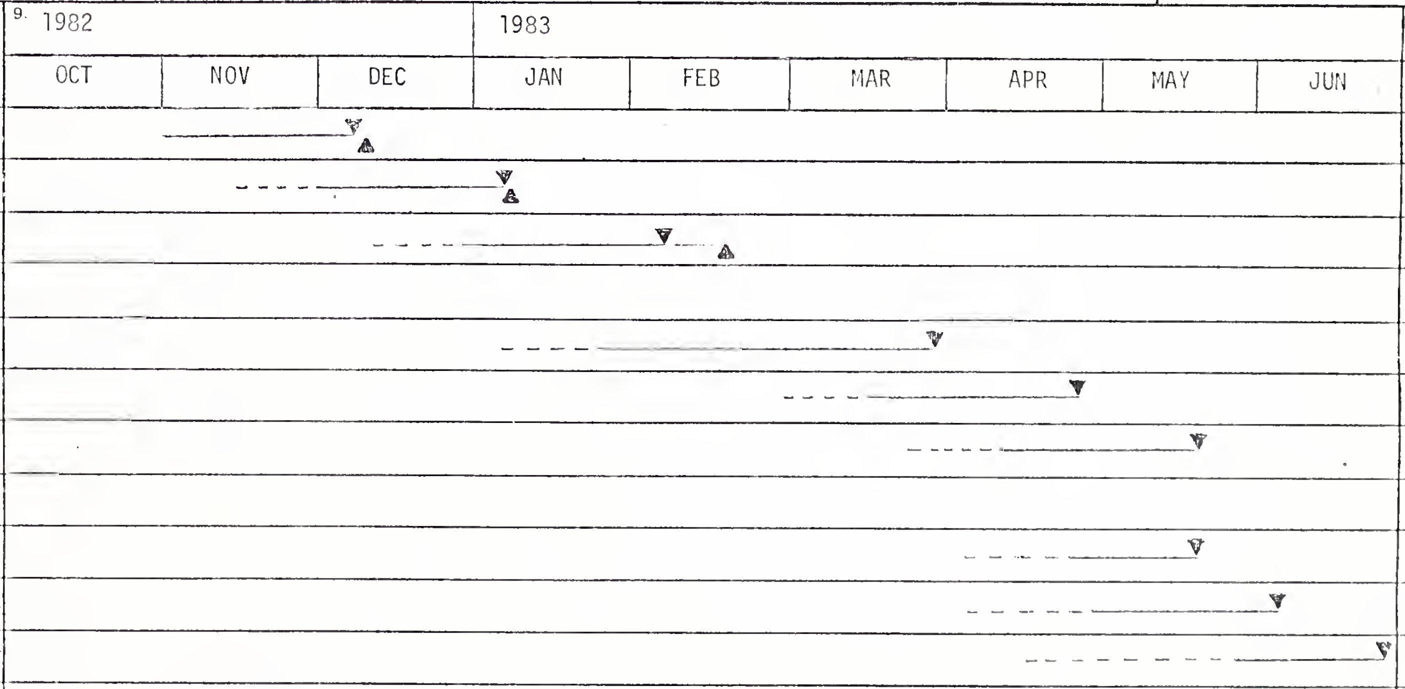
DIRECT LABOR	$23,802	
FRINGE	9,938	$33,740
LABOR OVERHEAD		12,298
OTHER DIRECT COST		
Consultants	8,700	
Travel	3,000	
Computer Service	1,000	
Reproduction	0	
Materials and Supplies	200	12,900
Direct Costs		$58,938
GENERAL AND ADMINISTRATIVE		12,062
COST		$71,000
FEE		5,062
PRICE		$76,062

ATTACHMENT #9

MILESTONE SCHEDULE AND STATUS REPORT

PAGE OF

1. Contract Identification Department of Natural Resources and Conservation	2. Reporting Period through	3. Contract Number
4. Contractor (name, address) Mountain States Energy, Inc. P. O. Box 3767 Butte, MT 59702		5. Contract Start Date November 1, 1982 6. Contract Completion Date June 29, 1983



7. Identification Number	8. Reporting Category (e.g., contract line item or work breakdown structure element)	10. Percent Complete a) Planned	b) Actual
DNRA	DETERMINATION OF PLANT TO BE USED FOR RETROFIT		
DNRB	SPECIFICATION OF BASELINE CONFIGURATION		
DNRC	CONFIGURATION ANALYSIS		
DNRD	DETERMINE DESIGN REQMTS		
DNRE	REVISION OF DESIGN REQUIREMENTS		
DNRF	COST AND SCHEDULE ESTIMATES		
DNRG	IMPACT ON NATIONAL MHD DEVELOPMENT PROGRAM		
DNRH	DRAFT ENGINEERING ASSESSMENT		
DNRI	ISSUE ENGINEERING ASSESSMENT		

11. Remarks

12. Signature of Contractor's Project Manager and Date

IDENT NUMBER	DESCRIPTION	SCHEDULED START	ACTUAL START	SCHEDULED COMPLETION	ACTUAL COMPLETION
1. DNRA	DETERMINATION OF PLANT TO BE USED FOR RETROFIT SC - INITIATION OF CONTRACT WORK AS AUTHORIZED BY THE DEPT. CC - OBTAIN EEI CONCURRENCE AND SELECTION OF CANDIDATE MONTANA PLANT	11-01-82	11-01-82	12-07-82	12-10-82
2. DNRB	SPECIFICATION OF BASELINE CONFIGURATION SC - SUCCESSFUL COMPLETION OF MILESTONE 1 AS INDICATED BY DEPARTMENT APPROVAL CC - THE ISSUANCE OF PRELIMINARY BASELINE SPECIFICATION TO BE USED FOR FOLLOW ON WORK	12-01-82	12-13-82	01-06-83	01-07-83
3. DNRC	CONFIGURATION ANALYSIS SC - SUCCESSFUL COMPLETION OF MILESTONE 2 CC - THE ISSUANCE OF A PLANT CONFIGURATION TO BE USED FOR FOLLOW ON WORK	12-29-82	01-03-83	02-09-83	02-18-83
4. DNRD	DETERMINE DESIGN REQUIREMENTS SC - SUCCESSFUL COMPLETION OF MILESTONE 3 CC - ISSUANCE OF A DRAFT DESIGN REQUIREMENTS TO TEN UTILITIES FOR CONCURRENCE	01-27-83	01-31-83	03-30-83	
5. DNRE	FINALIZATION OF DESIGN REQUIREMENTS SC - SUCCESSFUL COMPLETION OF MILESTONE 4 CC - OBTAIN UTILITY CONCURRENCE	03-14-83		04-26-83	
6. DNRF	COST AND SCHEDULE ESTIMATES SC - SUCCESSFUL COMPLETION OF MILESTONE 5 CC - ESTIMATED COST OF MHD RETROFIT AND SCHEDULE FOR RETROFIT ACCOMMODATION	04-11-83		05-17-83	
7. DNRG	IMPACT ON NATIONAL MHD DEVELOPMENT PROGRAM SC - COMPLETE MILESTONE 5 OR APPROVED BY THE DEPARTMENT CC - RECOMMENDATION TO THE NATIONAL MHD PROGRAM	04-18-83		05-17-83	

	IDENT NUMBER	DESCRIPTION	SCHEDULED START	ACTUAL START	SCHEDULED COMPLETION	ACTUAL COMPLETION
8.	DNRH	DRAFT ENGINEERING ASSESSMENT				
		SC - COMPLETE MILESTONES 6 & 7				
		CC - ISSUE DRAFT ENGINEERING ASSESSMENT	05-02-83		06-07-83	
9.	DNRI	FINALIZE ENGINEERING ASSESSMENT				
		SC - COMPLETE MILESTONE 8				
		CC - ISSUE FINAL ENGINEERING ASSESSMENT	05-25-83		06-29-83	